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REFERENCE

Lane, B. H., 1935. Suggestions to authors of papers submitted for publication by the United States Geological Survey: U. S. Geol. Survey, Washington, D. C. (For sale by Superintendent of Documents, Washington, D. C., 25c.)

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RADIOCARBON DATING OF LATE-PLEISTOCENE EVENTS

RICHARD FOSTER FLINT and
EDWARD S. DEEVEY, JR.

ABSTRACT. Determination of age of fossil organic matter, based on its content of Carbon 14 as measured in the laboratory of W. F. Libby, has been applied to a number of late-Pleistocene samples. Generally speaking, the results are highly encouraging, and lead to the belief that the new method is a valuable tool for the construction of a chronology. Many of the samples assayed, however, were unsatisfactorily fixed as to stratigraphic position, and the figures do not at once provide a complete and incontrovertible time-sequence. Apart from stratigraphic errors and uncertainties, the new method itself is subject to several kinds of error, the seriousness of which cannot be evaluated.

The stratigraphic horizon whose date is most securely established and which provides the soundest clue to the validity of other more questionable dates is the Two Creeks horizon in Wisconsin, representing a forest overwhelmed by the advancing Mankato glacier. Five samples agree within satisfactorily narrow limits in placing the age of this material at 11,400 years, so that in round numbers the Mankato maximum in Wisconsin probably was attained 11,000 years ago. Four samples from the Alleröd horizon in Germany, England, and Ireland give an age averaging about 10,800 years. As this horizon (Zone II of European pollen stratigraphers) underlies solifluction deposits assigned to the Fennoscandian glacial substage, the essential agreement of the dates implies that deglaciation of northern Europe was contemporaneous with that of North America.

Events antedating Two Creeks time have not yet been dated precisely, although the method is believed to be sensitive enough, and the Cary maximum is believed to have been recent enough, to fix the age of the Cary substage when suitable samples can be found. Several samples from older stratigraphic horizons give minimum ages, older than a figure ranging from 16,000 to 20,000 years, which are in agreement with their stratigraphic positions.

The meaning of a number of dates for post-Mankato-maximum events can be assessed only in the light of the pollen chronology. As this chronology is a relative one, based on climatic changes and vegetational responses during deglaciation, its calibration will require samples from many more localities. All of the dates are of the right order of magnitude, with a few exceptions where it seems likely that the stratigraphic position of the sample, and not the radiocarbon age, has been incorrectly given. Most of the available dates, unfortunately, represent isolated determinations that could be either "right" or "wrong" without necessarily affecting confidence in the method itself. The most important and interesting results are these:

The postglacial spread of forests, and of Mesolithic cultures adapted to forests, took place in England about 9,000 years ago. The time of attainment of the Boreal type of climate, *i.e.* the time of the pine zone, differed appreciably according to the latitude of the locality. The pine zone is about 9,000 years old in West Virginia, about 8,000 years old in Connecticut, and about 6,000 years old in Maine; it is about 8,000 years old in southern Minnesota and about 7,000 years old in northern Minnesota. The age of the thermal maximum ("climatic optimum") has not been precisely fixed, but several samples from horizons not far from it give ages ranging from about 6,000 to about 3,000 years ago. In addition to pollen-dated peat and gyttja from Connecticut and the British Isles, samples within this time range date the eruption of Mount Mazama in Oregon and bracket the Boylston Street fishweir in Massachusetts.

INTRODUCTION

THE method of dating specimens of wood, peat, charcoal, and other organic materials by measuring the residual concentration of Carbon 14 they contain has been described by W. F. Libby and his associates (Libby, Anderson, and Arnold, 1949). The method was checked through its use in dating ancient Egyptian objects whose ages were already known within narrow limits. Its accuracy was found satisfactory in these cases (Arnold and Libby, 1949).

The next step was to check the method against stratigraphically dated materials, both archaeologic and geologic, of greater antiquity. For this purpose a committee to procure and screen samples was set up by the American Anthropological Association. The committee consisted of Frederick Johnson (chairman), Donald Collier, Froelich Rainey, and Richard Foster Flint. The last-named member was designated by the Geological Society of America as its official representative. The committee named several collaborators, among them E. S. Deevey, representing special areas of knowledge. The committee kept in close touch with the laboratory at the Institute for Nuclear Studies, where the dating was done, and both directly and through its collaborators maintained a voluminous correspondence with sources of important material. At first fossil bones, teeth, and shells were assayed in addition to wood, peat, and charcoal, but the results were unsatisfactory. It was inferred that chemical exchanges had occurred in such materials, altering the amount of carbon present chiefly through the leaching and deposition of carbonates, and the assay of calcareous material was abandoned.

By September 1, 1950, a large number of dates had been determined, and it was agreed that Libby would present an

expanded report on the method while the committee would prepare a summary report (Johnson and others, 1951) on this group of dates. At the same time members of the committee and collaborators were authorized to publish more detailed reports on the stratigraphic significance of various groups of dates. The present paper is one of those reports. It discusses the geologic material dated, mentioning only those archaeologic samples that have a bearing on the geologic record.

The report is in no sense definitive; it is only a report of progress. The data on which it is based are limited in various ways, and some of the limitations can be overcome as the research continues. The foremost limitation is that very few dates more than 12,000 years ago have been determined as yet. A number of minimum dates greater than this have been obtained, but their usefulness is only partial. It is thought probable that refinements of the method will lead to the dating of material as much as 30,000 years old, but such work still lies in the future. Other limitations were imposed by lack of time for collecting and assembling materials for dating. Many samples had been collected many years earlier for other purposes, and stratigraphic descriptions in some cases were inadequate. Some samples, otherwise excellent, came from stratigraphic positions whose correlation was open to doubt through lack of adequate exposure. Conversely, some key deposits whose stratigraphic positions were firmly fixed were searched for wood or peat without success. Bones, teeth and shells, carefully collected and submitted for dating, proved for the time being at least, to be useless. Finally, quantities of material were offered by well-meaning people whose understanding of the rigid limitations involved was imperfect; this alone imposed a heavy burden of correspondence on the committee.

In consequence of these difficulties the results are very spotty and in some respects unsatisfactory. The spottiness is a consequence of the committee's having had to accept what it could get, for it was able to insure the directed field collecting of geologic materials, for dating purposes alone, in only about twenty instances.

Specific attention should be called to five possible sources of error in the date of any sample. These are: (1) Error in fixing the stratigraphic position of the sample. (2) Post-depositional

alteration in the proportion of Carbon 14 to total carbon by chemical change and possibly organic activity. (3) Predepositional variation in the steady-state ratio of Carbon 14 to Carbon 12 in organic matter, including the untested possibility that aquatic plants, deriving some of their carbon from freshly dissolved ancient carbonates, may show falsely low values of the ratio. (4) Contamination during or after collecting. (5) Laboratory error, including contamination. Of these five sources of error, the first involves no necessary error in the date obtained; it merely creates a discrepancy between the actual date and the stratigraphic date. The other four involve errors in the actual date itself.

It is believed that these sources have been avoided in the main, but until more dating has been done, the dates here discussed are accepted only provisionally, even though it seems probable that most of them are of the right order of magnitude. It should be pointed out that the laboratory errors assigned by Libby are based on the standard deviation expected in counting random events, and that in a large number of such determinations the limits of error quoted will be too narrow in an appreciable number of cases. Thus we may be sure that some of the dates are erroneous, but only additional work can show which ones they are.

CHIEF GENERAL RESULTS

The dates obtained, as of November 1, 1950, for samples having geologic, as contrasted with archaeologic significance, are listed in the Appendix. From them two general results have emerged. The first is that nearly all the dates fall into the same order as the relative stratigraphic position of the samples from which they were determined. This encouraging result leads to the inference that most of the dates reached are acceptable, although there are at least two exceptions that seem wholly inharmonious with their reported stratigraphic relations.

The second general result is that the dates of events late in the Wisconsin age have proved to be rather consistently less than the dates assumed before the radiocarbon method was employed. Thus the Mankato glacial maximum, earlier assumed to date from 25,000 years ago, has proved to date from about 11,000 years ago. This result seems to have been anticipated by the opinions of some geologists and soil scientists, who

had come to believe that the degree of soil development and erosion on the Mankato drift sheet are inconsistent with an age as great as 25,000 years. The shortening of our concept of the time since the Mankato ice began to melt away requires merely that we revise upward our notion as to the rate of melting. The whole process of deglaciation seems to have been more rapid than had been supposed.

Because the age of the pre-Mankato Two Creeks forest bed seems most securely established by five radiocarbon analyses, and because of the key position occupied by the Mankato substage in late-Pleistocene stratigraphy, we discuss this horizon first. We turn then to later events, dated with greater or less certainty. Horizons antedating the Cary-Mankato interval have so far been given minimum ages only, and as they are of less interest for this reason we discuss them last.

CARY-MANKATO INTERVAL AND ITS CORRELATIVES

Two Creeks horizon and Mankato substage. Of all the geologic dates thus far determined by radiocarbon, the most firmly established and probably the most widely significant is that of the Two Creeks horizon in Wisconsin. The stratigraphic position of the horizon is known, and from its date can be derived that of the maximum of the Mankato glaciation.

The salient facts about this deposit are here abstracted from the excellent studies by Wilson (1932; 1936). The deposit is exposed in wave-cut cliffs of Lake Michigan, at several localities in northern Manitowoc County, Wisconsin. These localities lie roughly 25 miles inside the extreme outer limit of the Mankato drift sheet. The horizon consists of peaty material, only a few inches thick, overlying, in one exposure, varved sediments probably deposited during the Glenwood phase of Lake Chicago (Cary substage). The peat underlies lacustrine sediments, in turn overlain without break by Mankato till. The peat is thus post-Cary, and it also antedates the Mankato maximum.

The peat contains much spruce wood, occurring both as stumps rooted in place and as prone logs mostly lying with their tops pointing southwest, the direction of flow of the Mankato glacier. Most of the logs are imbedded in the lacustrine sediments overlying the peat, and the majority of them are splintered at their butt ends, indicating that they were

broken off and pushed over while they were parts of living trees. The oldest tree observed had 142 annual growth rings, and a large number of logs revealed through their rings a decrease in rate of growth during the last few years of life.

In the top of the underlying varved sediments occur 3 species of mollusks whose ecologic relations suggest that the peat layer began to form as soon as emergence of the area from beneath the water of Lake Chicago permitted. The base of the peat consists mainly of grasses and arctic mosses, merging immediately into spruce, recording spruce-bog conditions like those common in northern Minnesota today.

The upper part of the peat includes lacustrine silt that filtered down between upright growing mosses, and the accompanying flora and fauna indicate wet ground. Hence the spruce bog was flooded for a time. Thereafter the margin of the Lake Michigan lobe of the ice sheet, in its Mankato readvance, overwhelmed the Two Creeks bog, snapping off the trees, pushing them over, and burying the site beneath till as the ice margin advanced 25 miles beyond the bog to its extreme Mankato position.

The whole sequence appears to be conformable, and to represent an interval of perhaps no more than a few hundred years at most. The varved sediments beneath the peat are not leached of their carbonates; this fact too suggests that the Cary-Mankato interval at this locality was short. Both the implied short interval and the ecology of the bog suggest that deglaciation was probably not extensive; the ice sheet margin may have retreated no farther than the sites of the northern shores of the existing Great Lakes.

The dates obtained are these:

Laboratory No.	Description	Collector	Date (years)
308	spruce wood	L. R. Wilson, 1949	10,877 ± 740
365	root of spruce tree	J. H. Bretz	11,437 ± 770
366	peat in which No. 365 was rooted	J. H. Bretz and Leland Horberg	11,097 ± 600
536	spruce wood	J. H. Bretz and Leland Horberg	12,168 ± 1,500
537	peat	J. H. Bretz and Leland Horberg	11,442 ± 640
		Average	11,404 ± 350

From the laboratory point of view the agreement among these samples is considered satisfactory (Arnold and Libby, 1950, p. 12). It adds weight to the reliability of the result. Hence the Two Creeks peat, being closely fixed stratigraphically and well dated chronologically, can properly serve as a key horizon to which other features and events can be related.

It is evident that the Mankato maximum must be younger than the time of death of the Two Creeks spruce trees, by the number of years taken by the glacier margin to advance from the Two Creeks locality through a 25-mile distance to its outermost position. The rate of advance, and the possible fluctuations of the ice margin during the advance are unknown. Hence the time assignment must be arbitrary. Any estimate is limited by the dates of samples nos. 332 and 334, discussed elsewhere in this paper. A figure of 200 to 400 years seems reasonable. If the larger figure is adopted, then, subtracting it from the average date for the overriding of the Two Creeks horizon, we get a round figure of 11,000 years for the Mankato maximum. This is a more useful date than the Two Creeks date, because the latter can be applied only where nonglacial features are exposed between the Cary and Mankato drift sheets, whereas the position of the Mankato drift border is known throughout a wide belt of country extending from southern Ontario to North Dakota. If it can be established by dating additional suitably situated samples that the ice sheet reached this position at about the same time at all longitudes, the drift border could be a very useful time marker.

The well-known estimates made by Kay (1931) as to the dates of the glacial and interglacial ages were based on depths of alteration of tills to gumbotil, assuming a uniform rate of alteration and assuming that the Mankato maximum occurred 25,000 years ago. That the latter assumption is too great by a factor of more than 2 is now known, thanks to radiocarbon dating. However, reduction of the date of the Mankato maximum from 25,000 years to 11,000 years affords no sound basis for recalculating the dates of events earlier in the Pleistocene, because Kay's first assumption is subject to error, as he himself noted. For this reason Kay's results were speculative, and radiocarbon developments make them no less so.

Alleröd horizon. Recognized originally at Alleröd in Sjaelland (Hartz and Milthers, 1901) from intercalation of a

band of organic lake mud in late-glacial *Dryas* clays, the Alleröd warm interval as established in pollen diagrams is now known to have a wide distribution. Increasing attention on the part of European workers to the non-tree component of the pollen flora (Firbas, 1934, 1949) has brought forward as the chief criterion for the recognition of this interval a decline from the high values (often several hundred percent of total tree pollen) characteristic of the treeless tundra to values under 100 percent. An increase of locally derived birch pollen is often found to have occurred at the expense of pine pollen blown from a distance, and an abundance of macroscopic fossils establishes the reality of the phase of comparative warmth. A subsequent interruption in the postglacial warming of the climate, recorded by a second maximum of non-tree pollen types and of fossils of such tundra plants as *Dryas*, is a normal feature of the geologic sections, and usually the change to the second cold phase is also marked by a shift from lake mud or peat to clay or sand, implying solifluction. In Denmark and the British Isles (Jessen, 1949) the threefold division of the "Late-Glacial" is designated by pollen zones I to III, II being the Alleröd layer. The late-Pleistocene stratigraphy recognized by the writers is shown in table 1.

As the Alleröd sediments are nowhere overlain by till, their areal distribution is significant for their correlation. They occur in a broad belt of country from Russia to Ireland, including southern Sweden and southern Norway, but, as shown by Schütrumpf (1943), they are unknown north of the central Swedish moraines and their correlatives. A warm interval of similar character is shown by pollen diagrams from the north flank of the Alps (Firbas, 1949). The pattern of occurrence implies that at places near but beyond the limits reached by the latest ice advance Zone III is the equivalent of till. The contemporaneity of the last sub-age of the Würm glacial age in the Alps with the last advance of the Scandinavian Ice Sheet, here assigned to the Fennoscandian sub-age, is not established, but the widespread similarity of pollen stratigraphy in northwestern Europe argues for the contemporaneity of the Alleröd deposits themselves. At several places in northern Germany the Alleröd layers contain a recognizable stratum of volcanic ash derived from the Eifel district. Remains of the early Mesolithic Ahrensburg and Lyngby cultures are stratified

Table 1

Summary of late-Pleistocene stratigraphy, with tentative correlations between North America and Europe

Central and Eastern North America		Western and Northern Europe				
Substages	Pollen Zones (New England)	Substages	DeGeer Terminology	Blytt-Sernander Terminology	Pollen Zones (British Isles)	Cultures
	C3 Oak-Chestnut		Postglacial	Sub-Atlantic	VIII Alder-Birch-Oak	Iron Age, Bronze Age
	C2 Oak-Hickory			Sub-Boreal	VIIb Alder-Oak	
	C1 Oak-Hemlock			Atlantic	VIIa Alder-Oak-Pine	Neolithic
	B Pine			Boreal	VI Pine-Hazel V Pine	Younger Mesolithic (Ertebölle)
	A Spruce-Fir		C-Varve 6839 B.C. Finiglacial	Pre-Boreal	IV Birch-Pine	Older Mesolithic (Maglemose, etc.)
Mankato	L3[2]	Fennoscandian[3]	8109 B.C. Gotiglacial	Arctic	III Younger Tundra	Ahrensburg, Lyngby
Two Creeks Horizon	L2[2]	Alleröd Horizon		Sub-Arctic	II Alleröd Birch	
Cary[1]	L1[2]	Pomeranian[1]	Daniglacial	Arctic	I Older Tundra	Magdalenian

[1] As it is not certain which European moraines should be correlated with the Cary substage, the table shows one possibility for purposes of orientation only.

[2] "L" stands for late-glacial tundra zones, which antedate Zone A in northern Maine and may therefore antedate the Mankato (Deevey, 1951).

[3] Presumed equivalents: Salpausselkä, central Swedish moraines, valley glaciation in British Isles.

into Zones II and III at several places. Moreover, the areal and stratigraphic relations strongly suggest an equivalence between Zone III and the Mankato substage, so that the Alleröd horizon should be of Two Creeks age.

The support given to these correlations by radiocarbon dating is the most important achievement of the new method. Zone II dates so far available are as follows:

337	Lake mud with *Betula* remains, 0-4 cm. above the volcanic ash layer, collected by Franz Firbas from a bog at Wallensen im Hils, Hannover.	11,044 ± 500
341	Lower peat bed in kaolin pit at Hawks Tor, Cornwall, underlying a gravelly solifluction soil containing a cold flora. Furnished by H. Godwin.	9,861 ± 500
444	Organic mud in an exposed profile at Neasham, near Darlington, Northumberland. Collected by K. M. Blackburn, furnished by H. Godwin.	10,851 ± 630
349	Calcareous silty lake mud, collected by Hiller peat sampler at Hockham Mere, Norfolk. Furnished by H. Godwin.	6,555 ± 280
355	Lake mud at Knocknacran, County Monaghan. Collected by G. F. Mitchell; furnished by H. Godwin.	11,310 ± 720

Excluding no. 349, the only one not collected by excavation from an exposed profile, the figures are consistent in indicating a date of about 10,800 years for the Alleröd horizon. (The unreliability of the method of multiple sampling with a peat sampler is discussed in a later section.) The average figure, 10,767 years, is 637 years younger than the average for the Two Creeks material, but the range of values overlaps to such an extent that the two horizons can be thought of as contemporaneous. Moreover, in the British Isles, where Zone III records the readvance of valley glaciers independent of each other and of the Scandinavian Ice Sheet, the correlation of Zone II with the Alleröd layer has heretofore been open to criticism. The agreement of radiocarbon dates in Germany, England, and Ireland provides the first substantial evidence for the matching of stratigraphic columns across so great a distance.

The dates assigned to the Gotiglacial retreat from the south Swedish to the central Swedish moraines (16,500 to 10,000 years) by De Geer (1940 and earlier papers) imply a discrepancy of about two thousand years in the age of the Alleröd. This part of the varve chronology has been shown by Hansen (1940) to be in error on quite other grounds.

The fact that the "radiation curve" of Milankovitch fails to

show a minimum corresponding to the Fennoscandian substage has been employed (Welten, 1944) as an argument against the use of this curve for dating Pleistocene events, a procedure espoused particularly by Zeuner (1945). Zeuner (1948) maintained that the Fennoscandian substage had never been regarded as caused by a radiation minimum, but instead was the result of a temporary increase in precipitation in the Baltic region consequent on reduction of the diameter of the Scandinavian Ice Sheet and of the intensity of its anticyclone. He called attention (1945, p. 157) to the fact that the diameter of the glacier at that time was about 1000 km., agreeing closely with the minimum size deduced by Brooks (1949, p. 65) for active growth of an ice sheet. The transatlantic correlation provided by the radiocarbon dates argues against a special explanation of this sort, inapplicable to the much larger Laurentide Ice Sheet of Mankato time.

It is legitimate to expect that events assigned to the Daniglacial or Brandenburg-Pomeranian interval in Europe will prove contemporaneous with events in the Tazewell-Cary interval in North America, if and when events so ancient become accessible to radiocarbon dating. Deposits corresponding to the older of two levels of Alleröd character, known to occur in several sections in East Prussia (Gross, 1937) and Norway (Faegri, 1940), should be among the first materials selected for investigation.

Mankato correlatives. Several samples, whose stratigraphic relations had led to the belief that they were to be correlated with the Mankato substage, were dated; the resulting dates justified the tentative correlation.

The first of these is no. 385, wood taken from a log buried in sandy outwash near the mouth of the Missouri River. Its location was in a quarry on Taussig Road, Bonfils, Missouri, 2.25 miles east of the town of St. Charles (Robertson quadrangle). The log overlay a lag gravel resting on bedrock, and was overlain by 23 feet of outwash sediments, eolian sand, and loess. The outwash body constitutes a terrace, correlated with the Festus terrace of Robertson (1938, p. 179), with a top, at Bonfils, about 50 feet above the Missouri River.

The wood was collected by L. C. Peltier in 1949. M. M. Leighton and H. B. Willman of the Illinois Geological Survey

have correlated the Festus outwash with the Mankato maximum; this correlation was accepted tentatively by Peltier (L. C. Peltier, unpublished communication). The radiocarbon date, 12,148 ± 700 years, tends to confirm this opinion, although the date is perhaps slightly greater than might have been expected. If the full benefit of the margin of error is taken, the figure is reduced very nearly to the average date of the Two Creeks material. As the Bonfils log lies at the base of the Festus outwash, and therefore should date from the beginning of outwash deposition, correlation with the time when the Two Creeks bog was overwhelmed seems reasonable.

The second Mankato correlative consists of two samples of charcoal taken from human occupation horizons occurring in alluvial silt in a stream terrace at two adjacent sites in Frontier County, Nebraska. The occurrences are described in Schultz, Lueninghoener, and Frankforter (1948) and Schultz and Frankforter (1948). The samples were collected by C. B. Schultz, who tentatively correlated the inclosing alluvium as Mankato.

The results of dating are:

No. 470	Charcoal from Medicine Creek site	10,493 ± 1,500
471	Charcoal from Lime Creek site	9,524 ± 450

The dates, when compared with that of the Mankato maximum derived from the Two Creeks figures, bear out the correlation of the alluvium at the Nebraska localities with the Mankato substage.

The presence of man in North and South America as early as the Mankato maximum has long been suspected on inadequate evidence, notably the indubitable association of artifacts with remains of extinct mammals. One of the places where such an association is beyond doubt is Gypsum Cave, near Las Vegas, Nevada (Harrington, 1933), the mammal in this case being the sloth *Nothrotherium shastense*. Bones of the sloth were in turn associated with remains of horse and two species of camel. Two samples of sloth dung from the cave have been dated by radiocarbon analysis. No. 221 gives an age of 10,455 ± 340 years, and no. 222 an age of 8,527 ± 250 years. These dates suggest that the view that man was a comparatively early immigrant into America is well founded, and is not based on misleadingly late survival of mammals now

extinct. Similar evidence comes from Chile, where another sample of sloth dung (no. 484) from Mylodon Cave, Ultima Esperanza, is dated as 10,832 ± 400 years old. The sloth was not demonstrably contemporaneous with man in this cave, but a sample (no. 485) of burned bone of sloth, horse and guanaco, associated with human bones and artifacts in Palli Aike Cave 125 miles to the east (Bird, 1938), gives a date of 8,639 ± 450 years. 1*

POST-MANKATO-MAXIMUM EVENTS

Pollen-dated peat samples: general statement. Of the several approaches to the chronology of postglacial time in Europe, the only one available in 1948 in North America was that of pollen analysis. Mud samples (gyttja, not peat) from Upper Linsley Pond, North Branford, Conn., were the first pollen-dated samples collected and the first analyzed. They were obtained through the ice in February, 1948, near the site of the original boring in the center of the lake (Deevey, 1943). Suites of 29 to 32 separate samples at each of three depths were taken with a Davis peat borer slightly larger (1 inch diameter) than standard. Within the limits imposed by the length of the cores (about 15 cm.) and the possible non-horizontality of the bedding within the circle of sampling, the three older samples should and apparently do date three important events at this locality. The oldest (no. 39, 8,323 ± 400 years) came from 11.65 m., at the top of the high-pine Zone B, the next (no. 38, 5,159 ± 350 years) from 9.15 m., in the layer where beech pollen is relatively frequent, at the transition from oak-hemlock Zone C1 to oak-hickory Zone C2, and the third (no. 37, 1,800 ± 500 years) from the level of maximum hickory and minimum beech, the "culmination" of C2. A fourth sample, no. 36, was taken at the "upper surface" of the mud at 5.5 m. with an Ekman dredge, but Zone C3 is only one meter thick at this point, and the age (876 ± 250 years) merely shows that the dredge sank an appreciable distance into the soft bottom.

The pollen chronology (see Deevey, 1949, for a recent review) is based on a sequence of local climatic changes following deglaciation and on phytogeographic responses to such

* Bold face numbers refer to notes added in proof (see end of paper).

changes. It is therefore a relative one, impossible to calibrate at any one locality. The attainment of a given "pollen age" must have occurred later at stations situated farther north, in the general direction of glacier retreat. This statement may not apply to the time around the thermal maximum of post-glacial time, but within the latitudes glaciated in the Wisconsin age, there is reason to expect lags of several thousand years in the incidence of such events as the pine-pollen maximum or the first appearance of forest trees. Samples for radiocarbon assay should be of equivalent pollen age but obtained from widely scattered places, and this phase of the investigation was being planned in the spring of 1949 when Libby requested more material from Upper Linsley Pond.

In the absence of ice, a new site, at the edge of the lake, was chosen for the boring, a new pollen profile was drawn up, and suites of 59 to 70 samples were obtained, this time at four subsurface levels. Three (nos. 122, 120, and 119) were at essentially the same horizons as nos. 39, 38, and 37, and the fourth (no. 121) was in the middle of Zone C1.

Evidence of heterogeneity emerged when the two deeper samples of the new series (nos. 122 and 121) were assayed. Subsequent field work has shown that at this bog-margin locality younger wood has sunk through the sediments to find a false stratigraphic position. Meanwhile an examination of the statistical aspect of multiple sampling (Deevey and Potzger, 1951) has made it clear, not that the method is necessarily unreliable, but that it is very difficult to determine whether or not adjacent peat-borer samples are stratigraphically equivalent. No evidence of non-equivalence could be found in the original series from Upper Linsley Pond, whereas in the new series the two older samples certainly, and the two younger samples possibly, were contaminated. The two latter dates (no. 120, 5,305 $\pm$ 250, and no. 119, 2,141 $\pm$ 250 years) agree so closely with the others as not to affect the subsequent discussion.

Of the American pollen-dated samples collected by Deevey and his collaborators (nos. 37-39, 119-122, 332, 334-336), all but one (no. 335) were taken by multiple sampling. One of the English samples (no. 349) was also taken in this way. Therefore these samples are subject to possible errors in addition to the kinds already enumerated.

The Boreal pine zone.[1] The high-pine pollen Zone B is the best marked and most nearly universal of all features of North American pollen diagrams. Normally overlying a spruce-fir zone, and underlying the maxima of oak and other deciduous types, it records the first postglacial attainment of a warm, probably dry climate, and thus agrees closely in stratigraphic position and in climatic implications with the Boreal zone of the Blytt-Sernander European sequence and with Zones V and VI of later workers (see Jessen, 1949, for a recent discussion). Because of its wide distribution, and because it was expected to differ in age according to the latitude of the locality, the pine zone was selected for intensive study. Older sediments from lakes and bogs normally do not contain enough carbon to meet the existing requirements for dating.

No. 336 was collected by H. C. Darlington from the high-pine level between 12¼ and 12¾ feet at the site of the original boring (Darlington, 1943) in Cranberry Glades, W. Va. This bog lies at an altitude of 3,375 feet. It is one of the very few peat bogs occurring well outside the glaciated region, and its earliest sediments contain pollen of spruce and fir. The pine interval followed, just as in more northern sections, and was succeeded by feebly differentiated deciduous pollen intervals. The age of the pine zone here is 9,434 ± 840 years, and while this is the oldest date yet known for the pine climatic phase, it is significant that it does not antedate the Mankato maximum. It implies, though it does not prove, that conditions favorable for the formation of peat bogs existed as far south as West Virginia, not merely at some part of Wisconsin time, but as late as the Mankato sub-age.

The next date of interest, geographically and chronologically, is that of 8,323 ±400 years for the pine zone of Upper Linsley Pond, Conn., (no. 39), situated on drift which cannot be dated exactly but which is almost certainly pre-Mankato. A lag of about a thousand years is indicated for the attainment of a pollen age equivalent to that of no. 336. Almost as

[1] In accordance with stratigraphic practice, we distinguish carefully between *zone*, which is a layer, and the time represented by a zone, for which we use *climatic phase*, when climatic implications are considered, or the informal terms *time*, *interval*, or *episode*. Pollen stratigraphers have generally been careless about their usage in this matter, and customarily use the term *period* for the time corresponding to a zone. *Period*, like *stage* and *epoch*, belongs to a very much longer time interval than a pollen-zonated time, and cannot be used without causing confusion.

far again to the north, the highest part of the pine zone at 6.0 m. in Plissey Pond, Aroostook County, Maine, gives a date two thousand years younger still (no. 335, 5,962 ± 320 years). This sample was taken out in one piece by means of a special instrument (Deevey and Potzger, 1951). The exceptionally interesting stratigraphy of the Aroostook County lakes has been described (Deevey, 1951); as there is a typically European sequence of "late-glacial" zones, including a birch zone of Alleröd character, the suggestion was made that the latest regional ice advance (Mankato?) just failed to reach the lakes, but was reflected in a return to tundra climate. Unfortunately the mild-climate layers contain too little organic matter for radiocarbon dating of this zone. The late date for the considerably younger pine zone (probably appreciably later than the "culmination" of the climatic phase) supports the inference, still to be ranked as no more than a guess, that the deglaciation of Connecticut occurred long before the Mankato maximum. Another piece of evidence for this view comes from Urry's (1948) radium dating of the varved clay at Hartford, Conn., at 18,000 years. **2**

Two Minnesota samples from Zone B form a series parallel to nos. 336, 39, and 335. No. 332 was collected by Murray Buell at 8.5 m. in Cedar Creek Bog, Anoka County, Minn., at the site of profile 4 (Buell and Buell, 1941; Lindeman, 1941). Pollen studies of this bog, left unfinished by Lindeman at his death, are now at Yale University; as shown in figure 1, they were complete enough to permit selection of the desired level. Sample 334, of equivalent pollen age, was collected by J. E. Potzger at 8 feet in Johnson Camp Bog, situated in sec. 12, T. 64 N, R. 13 W, 14½ miles northwest of Ely, St. Louis County, Minn. The pollen diagram has been published and the validity of the sample discussed by Deevey and Potzger (1951). Both bogs lie on Mankato drift, and the 900-year gap between the sample dates (7,988 ± 420 and 7,128 ± 300 years, respectively) is in line with their geographic positions, which are about 220 miles apart. As a spruce-fir time of unknown length preceded the dates given at both localities, these figures do not necessarily imply that the retreat of the Mankato glacier margin over the intervening distance lasted 900 years. **3**

If we conclude that the pine time of North American pollen diagrams was attained between 9,000 and 6,000 years ago,

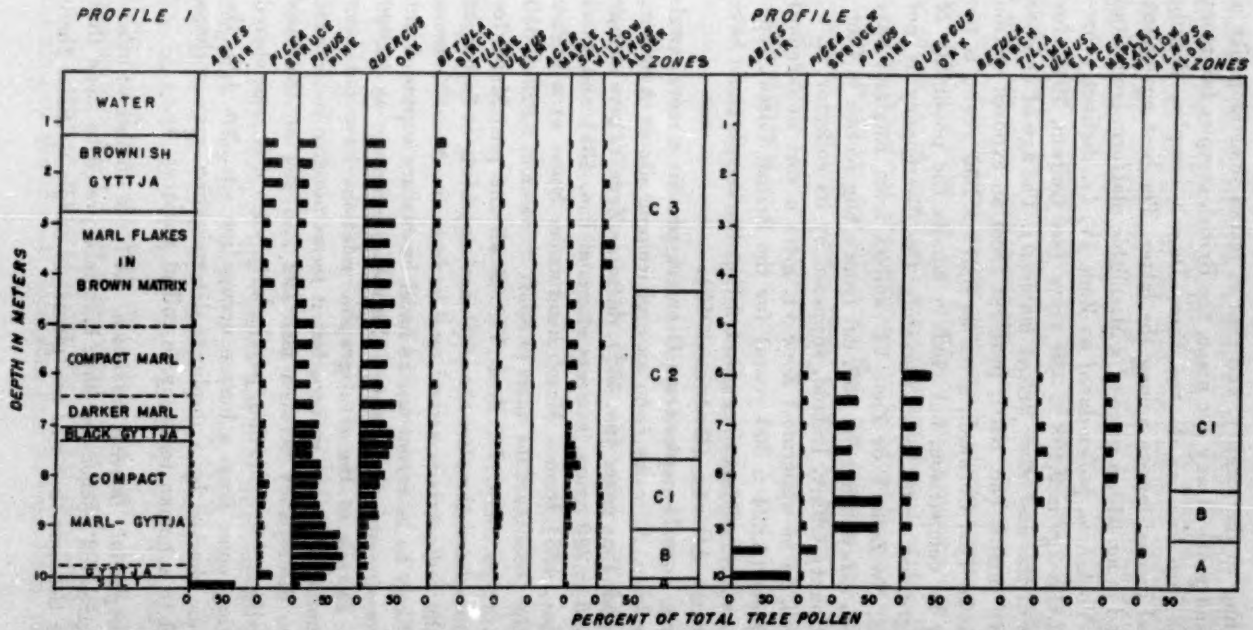

Fig. 1. Pollen diagrams from Cedar Creek Bog, Anoka Co., Minn., profiles 1 and 4, prepared from counts made by the late R. L. Lindeman. Profile 1 is the only one completed; radiocarbon sample no. 332 was taken at the site of profile 4 because of its greater accessibility in summer.

according to the locality, and that it lasted something like a thousand years at any one place, the British samples fall more or less into line, as do the three Danish samples, despite internal inconsistencies among the latter. The best agreement is found in no. 353, a piece of a Mesolithic platform from Star Carr, Yorkshire, pollen-dated as Zone IV, *i.e.* distinctly pre-Boreal. Its age is 9,488 ± 350 years (see Godwin, 1951, for details of this and other British material). The age of another Zone IV sample (no. 340), peat cut from an exposed section at Hawks Tor, Cornwall, given as 8,275 ± 350 years, is too young by comparison, but Godwin admits the possibility of stratigraphic error here; certainly the discrepancy is not serious. No Zone V or Zone VI samples from England have yet been assayed, but no. 358, cut from a bog section in Clonsast, County Offaly, Ireland, supposed by its collector, G. F. Mitchell, to be uppermost Zone VI, gives a sort of *terminus post quem* (5,824 ± 300 years) for the British Boreal, especially as Mitchell has since granted that the sample could have been early Atlantic (Godwin, 1951).

Three Boreal samples from Denmark present a more puzzling problem. All came from an archaeologic site at Aamosen, Sjaelland. Pine cones (no. 432), dated as Zone V, give an age of 7,583 ± 380 years, whereas charcoal (no. 434) and hazel nuts (no. 433) from a Mesolithic summer house at a higher level give the discordant dates of 8,631 ± 540 and 9,929 ± 350 years, respectively, for Zone VI. Of all the post-Mankato-maximum dates, these are the only ones suggesting at first sight that the radiocarbon method may be in error. No. 433 seems most likely to be erroneous, as hazel bushes are supposed not to have spread over northern Europe so long ago as 10,000 years. Details of the stratigraphic relations have not been communicated to the writers, but it seems possible to account for the discrepancy between nos. 432 and 434 on the basis of stratigraphic confusion, particularly when it is remembered that they come from a human occupation site. No. 433, the only one checked by a duplicate determination, may perhaps be laid to a human tendency to collect antiques. 4

"Postglacial" thermal maximum. A large number of otherwise unrelated phenomena have been interpreted to mean that during the time that was postglacial in middle latitudes there

was a climatic phase of higher temperatures than those of today. For this time we prefer the term *thermal maximum*, because we find the widely used term *climatic optimum* subjective and ambiguous. Events of particular significance for the present discussion are those tied to the pollen chronology.

1. The Littorina Sea invaded the Baltic basin, previously occupied by the Ancylus Lake, bringing maritime climatic conditions deep into northern Europe, and permitting the growth of such trees as elm and lime in places now apparently too cold for them. In the Blytt-Sernander scheme this phase is called the Atlantic. In places situated west of the Baltic, and removed from the influence of moisture-bearing westerly winds from over the Littorina Sea, the climate was moister than the preceding Boreal phase as well as warm; the statement applies not only to the British Isles, but to eastern North America.

2. Subsequently, in Sub-Boreal time, the climate of western Europe and eastern North America became drier while remaining warm. During this time, in western Europe at least, peat bogs became very dry, and the end of the interval is sharply marked by a horizon above which the composition of the peat indicates flooding, so general as to exclude causes other than climatic. This horizon, the *Grenzhorizont*, records the opening of the Sub-Atlantic time of cool, moist climate, with which are associated the end of the Bronze Age and the beginning of the Iron Age. Other boundary horizons or "recurrence surfaces" occur in bogs, each indicating a shift from dry to moist conditions. Five of them have been recognized in Sweden by Granlund (1932), and with varying degrees of success elsewhere. Ordinarily the most conspicuous is the middle one, RS III, and this is considered to be the same as the *Grenzhorizont* of north German bogs.

3. An episode of dry climate has been discerned in pollen diagrams from the Iowa prairie (Lane, 1931) as well as in the more arid Basin and Range Province (Hansen, 1947). The age of some lakes in the Province, as calculated from their salinity, is around 4,000 years. As these lakes are descendants of Pleistocene lakes, their youth has been accounted for by the widely accepted hypothesis that they went dry at the time of the thermal maximum (see Antevs, 1948, for re-

view). Matthes (1939, 1940) marshalled evidence that valley glaciers in many western mountain ranges underwent a parallel history of complete disappearance and rebirth. The stratigraphic evidence does not indicate whether the warm, dry interval west of the Rockies corresponds with all of the time from the beginning of the Boreal to the end of the Sub-Boreal in Europe, or with only part of it.

Absolute dates for the thermal maximum and associated phenomena have been used in Europe widely, in North America less so. These dates have been derived in a variety of ways. The varve chronology of deglaciation in Scandinavia, summarized by De Geer (1940), is a floating chronology, and Lidén's (1938) attempt to connect it with the present day involves an extrapolation. Although the counting of annual layers of gyttja in the Faulensee deposits (Welten, 1944) leads to impressive agreement with the De Geer-Lidén chronology, this sequence also requires extrapolation as well as interpolation, for many layers were missing. The archaeologic stratigraphy of western Europe is closely tied to the pollen chronology, but back of the cultures known to written history the assignment of absolute dates to archaeologic horizons rests on nothing more substantial than Lidén's extrapolation. Radiocarbon dating offers the first escape from a system of dates, which, however reasonable it may be, is supported more by universal opinion than by evidence.

The radiocarbon values so far available are too few in number to assist very much in ordering the various phenomena associated with the thermal maximum. No. 343 is a sample of humified *Sphagnum-Calluna* peat from the raised bog of Shapwick Heath, Somerset. The pollen age of this peat (Godwin, 1948; Clapham and Godwin, 1948) is Zone VIIb, Sub-Boreal; underlying it is a layer of *Cladium-Phragmites* peat belonging to Atlantic time (Zone VIIa), while the overlying transition to Sub-Atlantic conditions is marked, not only by the composition of the peat, but by a causeway, constructed in the late Bronze Age by people who were no longer able to cross the bog dry-shod. The radiocarbon age of 6,044 ± 380 years is later than the commonly accepted date of 7,500 years ago for the opening of the Littorina Sea, but about a thousand years too old if the peat is really Sub-Boreal. However, as the Atlantic-Sub-Boreal boundary is difficult to fix in pollen diagrams from

regions so maritime as the British Isles, this result can be accepted provisionally.

Another sample from the same heath, no. 347, falls in Zone VIII, and as this level overlies peat of the major episode of flooding (early Iron Age) and underlies the Romano-British occupation surface of the bog, it should establish the end of the phase of maximum temperatures. Two determinations of the age of this peat (3,099 ± 250 and 3,520 ± 300 years) are sufficiently discordant to suggest that the sample was too bulky to pinpoint the exact horizon desired, and if one subtracts the laboratory error from the younger date, the resulting figure of 2,850 years is probably close enough to the accepted date of 2,500 years for Recurrence Surface III. No. 450 supposedly came from just below the same horizon in a bog at Melbeck, near Lüneburg, Hannover. It was carefully excavated by Fritz Overbeck, and represents a layer two cm. thick immediately below the *Grenzhorizont*. Thus the horizon should have been pinpointed, and the remarkably close agreement between two runs (1,446 ± 250, 1,452 ± 290 years) indicates that it was, but the age is much too young. Possibly the layer actually sampled represents Granlund's Recurrence Surface II, dated at 400 A.D., and not the classic *Grenzhorizont*. The published sections (Overbeck and Schneider, 1938) permit this interpretation, but the confusion, if such it is, is not necessarily of more than local significance. 5

When we take account of the uncertainties of bog stratigraphy, and of the difficulty of collecting a bulk peat sample from a narrow horizon, the European dates are not out of line with the accepted figures for Atlantic and Sub-Boreal time (7,500 to 2,500 years ago). Sample 462, a piece of charred wood from a lake dwelling of supposed Neolithic "A" date, gives an age of 4,964 ± 300 years, and thus falls about where it should.

Data from the western side of the Atlantic are even more fragmentary, although they are not inconsistent with the stratigraphy so far as it is known. Sample 38, from Upper Linsley Pond, Connecticut, gives the reasonable figure of 5,159 ± 350 years for the transition from warm, moist (Atlantic?) to warm, dry (Sub-Boreal?) conditions, while the age of the sample from the level of the hickory maximum (no. 37, 1,800 ± 500 years) seems a little low for the Sub-Boreal.

Between these two dates we have the figure for the marine silt overlying the Boylston Street fishweir (Johnson and others, 1942, 1949): no. 418, 3,851 ±390 years. The Lower Peat (no. 417) at the fishweir site, which antedates the fishweir itself, gives the rather great age of 5,717 ± 500 years. The pollen stratigraphy at the fishweir site is inconclusive, but suggests that the structure was built shortly after the thermal maximum (Benninghoff, 1942; Knox, 1942; Wilson, 1949). One marine mollusk (Clench, 1942) from the deposits overlying the fishweir is a southern species and thus also implies a date around the thermal maximum. It is interesting to find that the radiocarbon results give ages a little higher than expected; the fishweir is only one of several archaeologic finds antedating a rise of sealevel on the Atlantic coast of North America, but salt-marsh peat from other such sites has not been submitted for dating, in the belief that the circumstances of its burial are exceptionally favorable to post-depositional exchange with younger carbon from sea water. If this exchange proves to be a chimera, a copious supply of such material is available for dating.

West of the Rockies, apart from the Gypsum Cave dates already discussed, and several other cave samples of supreme interest to archaeologists (Johnson and others, 1951), there are two samples connected (somewhat indirectly) with the pollen chronology. No. 247 consists of charcoal from a tree killed by the eruption of Mount Mazama, in the Cascade Range of Oregon (Williams, 1942); its age is 6,453 ± 250 years. No. 428 is a selection of sagebrush-bark sandals from Fort Rock Cave, Oregon, which were overlain by pumice from Newberry Crater (Cressman, 1942); they give the age of 9,053 ± 350 years.

Although the figures imply that the eruption of Newberry Crater antedated that of Mount Mazama by 2,500 years, this it not certain, and the confusion that arises from the dates can be clarified only by further work. The sandals and other artifacts of organic material in Fort Rock Cave were charred, possibly by hot pumice (Cressman, Williams, and Krieger, 1940; Cressman, 1942). Cressman has since stated (L. S. Cressman, unpublished communication) that the sandals assayed came from some distance below the pumice and thus do not date it precisely. Conflicting statements occur in the

literature (see Hansen, 1942, p. 105; 1947, p. 100) as to the relative ages of Newberry and Mount Mazama pumice. Evidence that some Newberry pumice is younger was published by Williams (1942, p. 69), and also by Allison (1945). Allison's sections from the basin of Summer Lake showed three layers of pumice interbedded with shallow-water sediments at an altitude some 80 feet above the modern lake. The oldest layer was assigned to Mount Mazama, the youngest to Newberry Crater, on petrologic evidence, while the middle one was not identified. The altitude of the exposures implies that the pumice falls occurred toward the end of the postpluvial shrinkage of Pleistocene Winter Lake. Evidence corroborating that from Summer Lake comes from Fossil Lake in the Fort Rock-Silver Lake basin and from Chewaucan marsh; three layers of Newberry pumice are now believed to postdate the climactic explosion of Mount Mazama (I. S. Allison, unpublished communication). The possibility remains that there were earlier series of pumice falls from Newberry Crater, for in the Summer Lake sections there were older layers of pumice that were poorly exposed and could not be examined.

Layers of pumice and volcanic ash are stratified in many of the pollen profiles published by Hansen (1947), but the distances between localities in most cases are so great and the pollen sequence is so little differentiated that the assignment of ages to the various eruptions on pollen-analytic grounds alone is hazardous. In the region where Mount Mazama pumice is well represented, in some cases underlying the bogs sampled, it appears that a phase of warm, dry climate was well under way when the pumice was deposited. The best evidence of the nature of the climate at this time comes from marked and long-continued maxima of grass and chenopod-composite pollen, for although Hansen relied on an increase of yellow pine pollen as indicating relatively dry conditions, the evidence that different species of pine can be distinguished quantitatively by their pollen grains is insufficient.

Leaving the question of the age of the pumice in Fort Rock Cave as unsettled, we may discuss the date of the explosion of Mount Mazama, apparently more securely fixed by no. 247. If the 215-foot level of Winter Lake corresponds to the Provo stage of Lake Bonneville, if these high levels represent the Mankato maximum, as is believed by Allison, Antevs, and

others, and if Mount Mazama pumice was deposited in a lake about 80 feet deeper than Summer Lake today, incorporation of the radiocarbon date of 11,000 years for the Mankato into Allison's argument indicates that the 6,500 year figure for Mount Mazama is entirely reasonable. It is consistent with the evidence that the volcanic explosion occurred after the beginning of the warm, dry interval of postglacial time, a climatic phase which may well have begun at the same time as the pine climatic phase in eastern North America. The writers know of no special reason for agreeing with the belief of Allison (unpublished communication) that sample 247 gives a falsely late date owing to post-depositional exchange of carbon.

The sandals from Fort Rock Cave are the oldest American artifacts yet assayed. Dates are also available for another early culture, the Cochise, in southern Arizona. The Sulphur Spring stage of the culture (Sayles and Antevs, 1941) consists of stone artifacts, and charcoal of hickory and cottonwood, imbedded in river sands and gravels laid down in an episode of alluviation. The same deposits contain bones of mammoth, horse, and dire wolf. As the culture material and the fossils have been carried by water, they are not necessarily contemporaneous with each other or with the alluviation, but the presence of hickory suggests a more humid climate than today, and the charcoal gives a radiocarbon date (no. 216) of 7,756 ± 370 years. Another charcoal sample (no. 511) from the same stage, but at a different site, gives an age of 6,210 ± 450 years. The Chiricahua stage of the culture occurs in alluvium apparently deposited in erosion channels cut in the older formation and containing fossils of modern vertebrates. Charcoal from this stage (no. 515) gives an age of 4,006 ± 270 years. The relation of the San Pedro stage to the Chiricahua is somewhat similar to that between Chiricahua and Sulphur Spring; charcoal from the San Pedro stage (no. 519) is dated at 2,463 ± 310 years. The sequence of episodes of alluviation during humid phases, separated by arroyo cutting during arid phases, is not without parallel in other parts of the arid western United States (Albritton and Bryan, 1939), and in the Davis Mountains region of Texas the oldest deposits also contained mammoth and horse bones, though no artifacts. It is not to be expected, however, that

such cycles were invariably contemporaneous in adjacent valleys, and in the Davis Mountains the youngest of the three bodies of alluvium contains pottery about 500 years old.

The chronology of events around the thermal maximum touches on widely different geographic phenomena, from peat composition and changing sealevel through volcanic eruptions to cycles of alluviation and erosion, and the material assayed for radiocarbon represents a small selection, taken almost at random. It is surprising that the dates obtained fit as well as they do with what was previously known or believed.

Mankato deglaciation. Two samples, not connected directly with the pollen chronology, seem out of line with the results presented so far. If the Mankato ice reached its maximum extent 11,000 years ago, and began its retreat soon afterward, so that the Boreal type of climate was attained within the area of Mankato drift in Minnesota 3,000 or 4,000 years later, it is difficult to account for the apparent presence of active ice in eastern Wisconsin some 6,000 years ago. No. 419 is a section of spruce log (*Picea glauca*) from laminated fine sediments within the limits of the Mankato drift sheet on the bank of Fox River in the SE ¼ SE ¼ sec. 3, T. 20 N., R. 17 E., north of Menasha, Winnebago County, Wis. The log was collected in 1925 by F. T. Thwaites, from an exposure made by a grader, and the stratigraphic relations were smeared and obscure. The log was exposed about ten feet below the surface, and was possibly but not certainly overlain by till. It was flattened as though overridden by glacier ice, and microscopic examination by E. S. Barghoorn (unpublished communication) revealed that the cell structure of the wood had been crushed. The growth rings, about 100 in number, are thin, suggesting slow growth and therefore probably a cold climate. No end moraines or other direct evidence of a readvance of the glacier margin have been recognized in the vicinity. Thwaites (1943, p. 136) inferred provisionally that the log is a correlative of the Two Creeks peat horizon, but later (F. T. Thwaites, unpublished communication) stated that it could postdate the Mankato maximum.

The date, 6,401 ± 230 years, 4,500 years after the Mankato maximum, seems altogether too late to warrant the hypothesis that the wood was overridden by one of the many reexpansions that characterized the shrinkage of the Mankato

glacier from its maximum position, as shown by the numerous Mankato end moraines. The locality is barely 25 miles inside the outer limit of the Mankato drift sheet, whereas no. 332, from a bog but little farther inside the area of Mankato drift, indicates that the pine climatic phase had already been reached 1,600 years earlier. If the dates are accepted, the difference would be explicable only on the assumption that the Mankato ice melted very much more slowly in Wisconsin than in Minnesota. That it did so is possible, but two alternative explanations have not been eliminated, namely that there has been contamination or laboratory error in the dating of no. 419, and that the log was crushed by some agency other than glacial overriding.

A discrepancy in the opposite sense is provided by no. 497, wood from a peat-like stratum in sediments ascribed to glacial Lake Agassiz at Moorhead, Minnesota. It was furnished by W. S. Cooper. We owe its description to Rosendahl (1948, p. 289-290), who identified the flora. Rosendahl did not himself see the exposure; his description paraphrases that of a local observer.

The exposure was created during a construction operation in the bank of the Red River. The wood apparently underlay 25 feet of laminated (possibly varved) lacustrine silt. At least 1,800 exposed laminae were reported. The contact of the lacustrine sediments on underlying till was believed to lie not far beneath the wood horizon. The wood was allochthonous, possibly having been carried into the lake by the Buffalo River. Rosendahl expressed the opinion that the wood was deposited "fairly early in the history of the lake." The floral assemblage proved to be similar to that living in the same district today.

After the Mankato maximum, for which we accept a date of 11,000 years, the glacier had to shrink so as to eliminate the massive Des Moines lobe, 300 miles long, before the Moorhead locality could be uncovered. Thus the wood, if actually deposited in Lake Agassiz, should be considerably younger than 11,283 $\pm$ 700 years, the date determined. If possible alteration, contamination, and laboratory error are set aside, there are still at least two other possible explanations of the discrepancy. The more likely is that the wood is a correlative of the Two Creeks horizon, and that it was washed out of its

first sedimentary matrix by the waves of Lake Agassiz and incorporated in the sediments of that lake. Upham (1895, p. 253) implied that driftwood of very late date is common in deposits along the Red River. The less likely explanation is that the Mankato ice reached its maximum substantially earlier in the Dakotas than in eastern Wisconsin.

History of the Great Lakes. Three more samples, nos. 191, 364, and 504, which also postdate the Mankato maximum, are related to each other because of their relations to the glacial Great Lakes. Their respective dates agree fairly well among themselves, although possibly all are younger than might have been expected.

No. 191 is charcoal, furnished by W. A. Ritchie from the stratigraphically lowest level of a human occupation site on Frontenac Island in Cayuga Lake, New York, 7 miles south of the northern end of the lake. The entire island is less than 20 feet above the lake surface. It can be inferred from Fairchild (1909, p. 59; plate 42), Leverett and Taylor (1915, pp. 409-445; plate 21) and Coleman (1936) that the basin of Cayuga Lake was filled with glacier ice or with lake water, above the level of the present lake, until well after Lake Iroquois had begun to be drained (by stages) by glacial melting north of the Adirondacks. It follows that Frontenac Island could not have emerged until that time, and that the earlier part of the draining of Lake Iroquois therefore occurred at least 4,930 ± 260 years ago, the date of the earliest known human occupation of the island.

From the same sources it appears that Lake Iroquois was drained while Lake Algonquin III[2] occupied the upper Great Lakes region. Hence it appears likely that Lake Algonquin III was in existence more than 4,930 years ago. The date does not imply that it was not in existence very much longer ago than that, and the fact that Lake Algonquin had an ice margin is not in conflict with the fact that 5,000 years ago was around the time of the thermal maximum.

[2] The following equivalents with earlier usage exist:

This paper	*Leverett & Taylor* (1915)
Lake Algonquin I	Early Algonquin (p. 412)
Lake Algonquin II	Kirkfield stage (p. 412)
Lake Algonquin III	Port Huron-Chicago stage (p. 413)
Lake Algonquin IV	Closing transitional stage (p. 438)

No. 504 is a sample of peat, collected by L. R. Wilson (Wilson, 1935) from beneath the surface of Lake Superior at Sand Island near the western end of the lake. The peat represents a flora similar to that now living in the region. According to Taylor (1931; see also Leverett and Taylor, 1915, plate 27) this layer of peat was formed, possibly in a lagoon, at or close to the level of the Nipissing Great Lakes during the very early, one-outlet phase of that water body.

If Taylor's correlation is accepted, the early Nipissing phase was in existence 3,656 ± 640 years ago. Subtracting this date from that obtained for no. 191 we get 1,274 years as the minimum elapsed interval between a time when Algonquin III existed and a time early in the history of the Nipissing lakes—an interval embracing an unknown fraction of Algonquin III time plus the time required for the evanescent Algonquin IV (Leverett and Taylor, 1915, p. 438) which marked the short transition from Algonquin III to Nipissing.[3]

No. 364 is a piece of an oak log occurring as driftwood in beach sand and gravel at Dolton, Illinois, at the southern end of Lake Michigan. J H. Bretz, who collected the sample many years ago, is unable to determine whether the inclosing beach sediments belong to the Toleston strandline of Lake Chicago, to the highest strandline group of Lake Algonquin, or to the highest strandline group of a late phase of the Nipissing Great Lakes. The uncertainty results from the fact that in the vicinity of Dolton all three groups lie within the narrow altitude range of 590 to 600 feet (Bretz, 1939, p. 111; unpublished communication; J. S. Olson, unpublished communication).

The date of the sample (3,469 ±230 years) precludes its assignment to Toleston Lake Chicago, which long antedates Lake Algonquin. The history of Lake Algonquin, inferred from the various references cited above, indicates that its highest strandlines at the southern end of Lake Michigan were made at the end of Algonquin III. But no. 364 is younger than no. 504, believed on good evidence to be early Nipissing. Even if we take the full benefit of the margins of error in the dates of these two samples—that is, add the error to the date for no. 364 (3,469 + 230 = 3,699) and subtract the error

[3] Stanley (1938, p. 966) suggested that additional events might be involved.

from the date for no. 504 (3,656 − 640 = 3,616)—we get a difference of only 88 years between latest Algonquin III and the earliest Nipissing phase. Within the limits of present very imperfect knowledge, this seems improbable. Hence the Algonquin correlation can be rejected at least provisionally.

This leaves the late-Nipissing correlation. Assuming that no. 364 is late Nipissing, and subtracting its date from that of no. 504, we obtain 187 years (neglecting specified errors) as the minimum time elapsed between the early Nipissing and late Nipissing phases. This figure is very small, but it does not seem impossible.

The entire scheme, of course, is predicated not only on the accuracy of the three dates concerned, but on stratigraphic correlations made at different times by several geologists. Many possible errors are involved. The stratigraphy of the three samples has been explored as a test, and whereas the agreement between the dates and the stratigraphy is very far from perfect, it is not wholly inconsistent. The recency of the dates is surprising at first glance, but the time sequence is not inconsistent with nos. 334 and 332, in terms of deglaciation since the Mankato maximum. The fact that these dates fit the relative stratigraphic positions of the corresponding deposits even as well as they do, lends credibility to their absolute as well as relative reliability.

The chief obstacle to accepting them may appear to be the existence of a body of salt water in the Gulf of St. Lawrence region, postdating lakes correlated with Algonquin IV. Some geologists will continue to believe that this series of dates implies impossibly great crowding of post-Mankato-maximum events in the Great Lakes region. This belief may be justified, and the doubt cannot be disposed of until more radiocarbon dating has been accomplished. But the history of the Gulf of St. Lawrence is known with too little certainty to stand in the way of the dates. If there was a sea of arctic character in that region, it was probably not the same sea that postdates Algonquin IV. Fossils from the vicinity of Ottawa include such comparatively warm-climate types as sugar maple, balsam poplar, and yellow birch (Baker, 1920, pp. 178-179), all of which would be expected to live in the same district today. The stratigraphy of the region needs to be thoroughly re-examined.

PRE-MANKATO DATES

A number of samples known or believed to antedate the Mankato maximum, one of them indubitably Illinoian or earlier, were assayed. Thus far all but one have proved to be beyond the reach of precise dating by the laboratory method used, although it is hoped that through the use of a more refined method, currently about to be tried, some of these can be dated. At present the dates can be quoted only as greater than a minimum figure, ranging from 16,000 to 20,000 years. The data on the samples tested are set forth in the following sections, arranged in order of increasing stratigraphic age.

Tazewell-Cary interval. No. 508 is a piece of a log imbedded in unaltered till and collected in 1950 by R. P. Goldthwait, who gave his opinion that the till is Cary. The occurrence is in the E ½ sec. 2, R. 6. T. 1., Montgomery County (6 miles south of Dayton), Ohio.

The log is one of several that probably record a forest overwhelmed by the advancing Cary glacier; therefore its age is presumably late in the Tazewell-Cary interval.

The wood is dated as >17,000 years old. This minimum date agrees with that of no. 481; as far as they go, these two dates agree with the stratigraphic interpretations on record.

No. 465 is a piece of a conifer log from an exposure in sec. 26, T. 4N, R. 1E., Butler County, near Hamilton, Ohio. The log was imbedded in unaltered till, about 50 feet below the surface of the till and of the ground. According to R. P. Goldthwait, who collected the sample in 1949, the till is either Tazewell or Cary. Therefore, the tree concerned was probably killed during the Tazewell or Cary advance.

The minimum date, >15,000 years, agrees fairly well with nos. 508 and 481, and is consistent with either of the two stratigraphic interpretations mentioned above.

No. 438 is a sample of peat furnished by E. R. Eller from a Wisconsin stream terrace on Chartiers Creek, near Bridgeville, Pennsylvania. The occurrence is fully set forth by Schopf and Cross (1947). The peat is related to ponding of the creek by an outwash fill in the Allegheny-Ohio drainage system. In a well-reasoned argument, Schopf and Cross stated the opinion that the peat dates from very late in either the Tazewell-Cary interval or the Cary-Mankato interval, probably the former.

The date, >16,000 years, confirms these authors in that it rules out the Cary-Mankato possibility and admits of the Tazewell-Cary possibility. This sample is expected to be somewhat though not greatly younger than no. 481.

Tazewell sub-age. No. 575 is a piece of wood from a pit in the SW ¼ sec. 9, T. 34 N., R. 4 E., La Salle County, Illinois. It was imbedded in lacustrine clay correlated with the Lake Kickapoo deposits of Tazewell age, overlain at this locality by Tazewell till. Hence the wood cannot be younger than Tazewell. The section has been described and illustrated by Willman and Payne (1942, p. 307). H. B. Willman, J H. Bretz, and Leland Horberg, all of whom are familiar with the local stratigraphy, concur in the stratigraphic position of the wood.

The date (>17,000) in consistent with those mentioned in the preceding paragraphs as pertaining to the Tazewell-Cary interval.

Iowan or Tazewell sub-age. No. 481 is a fragment of wood from the Mitchellville cut (NE ¼ sec. 1, T. 80 N., R. 22 W.), Polk County, Iowa. The wood was collected in 1950 by W. H. Scholtes of the Bureau of Plant Industry, U. S. Department of Agriculture. It was imbedded in loess 16 feet below the upper surface of the loess, which is capped by 2 to 3 feet of till. According to an unpublished communication from R. V. Ruhe of the Iowa Geological Survey the till is probably Cary and the loess is Iowan and Tazewell loess. The wood therefore may date from as early as Iowan time.

The date obtained for the wood is >17,000 years.

Farmdale horizon. No. 510 is a piece of wood collected in 1950 by G. D. Smith and C. S. Denny from an exposure one-quarter mile east of the classic Farm Creek exposure near Peoria, Illinois (Leighton, 1926). The wood was imbedded in loess formerly considered to be Sangamon soil but more recently regarded as Farmdale (very early Wisconsin) loess.

Little hope was entertained that this horizon would fall within the scope of the dating method used, and it does not. The date reached is >20,000 years.

Sangamon interglacial age. No. 105 is a piece of cypress stump from the Carolina coastal plain collected by Stephen Taber from a section exposed in the Intracoastal Canal near

Myrtle Beach, Horry County, South Carolina. The sample was taken from a stump rooted in peaty soil overlain by more than 15 feet of the marine Pamlico formation. Taber (unpublished communication) regarded the cypress-stump horizon as probably early Sangamon.

The Pamlico formation represents a sealevel about 25 feet above present sealevel, and a climate at least as warm as the present climate. Although it has been considered to be probably Sangamon, this formation has never been stratigraphically placed with accuracy. The date of no. 105, >20,000 years, throws a little light on the stratigraphic position of the Pamlico. Presumably the only time since the Sangamon age when the sealevel could have been higher than now was the thermal maximum of about 5,000 years ago. Such a figure is ruled out by the great age of no. 105. Hence the Pamlico is apparently at least as old as Sangamon.

No. 480 is a piece of oak wood from Cambridge, England, furnished by H. Godwin. It was imbedded in organic mud indicated by its fauna and flora, as well as by its relation to stream terraces, to be interglacial. It has been stated by Hollingworth, Allison, and Godwin (1950) that the mud probably belongs to the last (= Sangamon?) interglacial stage. The radiocarbon date, >17,000 years, is in accord with that probability.

Illinoian glacial age. No. 466 is a piece of wood from a log exposed in a creek bank in sec. 2, T. 19 N., R. 12 W., Vermilion County (near Danville), Illinois. It was collected in 1950 by H. E. Eveland, G. W. White, and H. B. Willman, from Illinoian till the surface of which had been converted to gumbotil. The position of the wood was 4.5 feet below the base of the gumbotil.

This sample was run as a check on the general accuracy of the dating method. It was expected that it would prove to be beyond the reach of the method used, and the expectation was fulfilled. The date obtained was >17,000 years.

Unknown pre-Mankato horizons. Several samples were assayed from horizons of unknown stratigraphic correlation. The first, no. 363, is a piece collected by Stephen Taber from a large cypress stump rooted in place on the Santee River about 2 miles downstream from the Santee-Cooper Dam,

Berkeley County, South Carolina, at an altitude of about 25 feet. The stump, representing a tree larger than any conifer now growing east of the Mississippi River, had been exposed by diversion works. Previously it had been under water, and terraces show that it had earlier been buried beneath about 30 feet of sandy alluvium, dated only (by Taber) as "probably Wisconsin or earlier to Recent." The geology of the district has been discussed by Taber (1939).

Possibly the tree was killed by alluviation in response to rise of sealevel during Sangamon time or some other time of high sealevel. The date obtained, >17,000 years, is consistent with the date of no. 105, definitely related to a rising sealevel higher than the present one.

No. 496, furnished by W. S. Cooper, consists of wood taken from a well at Bronson, Kittson County, Minnesota, in the region of Mankato drift. The collecting was properly supervised, for samples were taken at 2-foot intervals as the boring progressed. The well log (Rosendahl, 1948, p. 291-296) is as follows:

Lake Agassiz sediments	20 feet
Till	46 feet
Gravel, sand, and clay	22 feet
Peat	3 feet
Clay (lacustrine?)	16 feet
Boring ceased at	107 feet

Rosendahl identified the plant assemblage in the peat as representing a spruce-tamarack forest. Progressive decrease in the thickness of growth rings visible in sections of three branches was viewed by him as recording oncoming glaciation.

The obvious stratigraphic assignment of the peat, before radiocarbon dating, was to the Cary-Mankato interval. However, the radiocarbon date, >19,000 years, makes this improbable, at least until the date of the Cary maximum has been determined. It is more likely that the peat dates from at least as long ago as the Tazewell-Cary interval. The 46-foot thickness of till overlying the peat may of course consist of two tills in direct contact with each other. On the other hand, if the peat should prove to be Tazewell-Cary, and if only one overlying till is present, an interesting possibility arises.

Conceivably, the till represents both Cary and Mankato substages at a locality continuously covered by ice throughout the Cary-Mankato interval. With information from more localities, radiocarbon dating can perhaps throw light on the subject, little known hitherto, of the extent of deglaciation between the various substages of the Wisconsin glacial age.

Two samples from Singletary Lake, Bladen County, North Carolina, were collected by David G. Frey by means of multiple sampling with a peat borer. Three organic horizons are known from the sediments of this lake (Frey, 1951), two of them lying below and one lying above the uppermost inorganic horizon that contains a maximum of spruce and pine pollen. If the spruce-pine inorganic zone is of Mankato age, as Frey suggested, the lower organic layers from which the dated samples came should belong to the Cary-Mankato and Tazewell-Cary intervals. Both samples (nos. 475 and 476) prove to be older than 20,000 years, and therefore neither can be as young as the Cary-Mankato interval.

A sample from the upper organic layer, which Frey supposed to be post-Mankato, has not yet been assayed. 6

Another sample from England, no. 479, furnished by H. Godwin, should be mentioned here, as its stratigraphic position is not precisely fixed. It is from an arctic peat occurring as transported masses in gravel in the Lea Valley north of London. The gravel is identified as the Ponder's End horizon (Warren, 1915), believed to date from some time during the last (=Wisconsin?) glacial age (H. Godwin, unpublished communication). The date obtained, >20,000 years, is a minimum that compares well with the dates of all but one of the pre-Mankato samples from the United States. Hence it confirms expectation.

Summary. Unfortunately the majority of the pre-Mankato dates are not fixed except as to minima. Some of the samples are stratigraphically so ancient that their dates probably cannot be improved. Those believed to be Tazewell-Cary, however, are likely to fall within the range of the more refined radiocarbon dating method soon to be undertaken. The pre-Mankato date now most needed is a date as close to the Cary maximum as possible, so that the time relations of the last two glacial maxima can be determined.

CONCLUSION

The first extensive results of stratigraphic dating by radiocarbon have value and show great promise for the future. The results seem fully as good as the results of the uranium dating of rocks in the early days of the development of that method. The fact that most of the radiocarbon dates fall into the relative stratigraphic positions of the samples encourages belief that the method is reliable and that significant exchange variations in the proportions of Carbon 14 to total carbon within the materials sampled are not likely to have been great.

According to one's point of view, it is refreshing or discouraging to recall the number of instances in which a direct challenge, offered by a radiocarbon date to a previously published stratigraphic assignment, has resulted in significant modification or withdrawal of published statements and cherished views. At the same time, in some of the same instances, acceptance of the radiocarbon dates requires a mental balancing of probabilities that is suspiciously close to special pleading. The new method, like older stratigraphic methods, is subject to possibility of error, recognized and unrecognized, and at present it is impossible to be sure that any opinion about a date, favorable or unfavorable, is free from special pleading. It is therefore necessary, while giving general approval to the new chronology, to keep an open mind about every one of its specific applications.

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APPENDIX

Check list of samples and dates, arranged in order of laboratory number. The errors quoted correspond to the standard deviation ($\sigma = \sqrt{\text{number of counts}}$).

Number	*Description*	*Date (years before A.D. 1950)*
36	Gyttja, Upper Linsley Pond, Conn., 5.5 m., Ekman dredge	876±250
37	Gyttja, Upper Linsley Pond, Conn., 8.05 m., Zone C2	1,800±500
38	Gyttja, Upper Linsley Pond, Conn., 9.15 m., Zones C1-C2	5,159±350
39	Gyttja, Upper Linsley Pond, Conn., 11.65 m., Zones B-C1	8,323±400
105	Wood of cypress from beneath Pamlico formation, Myrtle Beach, S. C.	>20,000
119	Gyttja, Upper Linsley Pond, new series, 4.65 m., Zone C2	2,141±250
120	Gyttja, Upper Linsley Pond, new series, 6.65 m., Zones C1-C2	5,305±250
121	Gyttja, Upper Linsley Pond, new series, 8.65 m., Zone C1	6,911±250 4,088±250
122	Gyttja, Upper Linsley Pond, new series, 10.15 m., Zone B	6,668±250
191	Charcoal, Frontenac Island site, Cayuga Lake, N. Y.	4,930±260
216	Charcoal, Cochise culture, Sulphur Spring stage	7,756±370
221	Dung of ground sloth, Gypsum Cave, Las Vegas, Nev.	10,902±440 10,075±550
	Ave.	10,455±340
222	Dung of ground sloth from higher horizon at locality of 221	8,692±500 8,051±450 8,838±430
	Ave.	8,527±250

APPENDIX (*Continued*)

Number	*Description*	*Date (years before A.D. 1950)*
247	Charcoal, tree killed by eruption of Mt. Mazama, Ore.	6,389±320
		7,818±350
		5,988±400
		6,827±400
	Ave.	6,453±250
308	Spruce wood, Two Creeks horizon, Manitowoc Co., Wis.	10,877±740
332	Gyttja, Cedar Creek Bog, Minn., 8.5 m., Zone B	7,988±420
334	Peat, Johnson Camp Bog, Minn., 8 ft., Zone B	7,586±490
		6,866±350
	Ave.	7,128±300
335	Gyttja, Plissey Pond, Me., 6.0 m., Zone B	5,962±320
336	Peat, Cranberry Glades, W. Va., 12¼-12¾ ft., Zone B	9,434±840
337	Gyttja, Wallensen im Hils, Hannover, Germany, Zone II	11,044±500
340	Upper peat, Hawks Tor, Cornwall, England, Zone IV	8,011±400
		8,540±780
	Ave.	8,275±350
341	Lower peat, Hawks Tor, Cornwall, England, Zone II	9,861±500
343	Peat, Shapwick Heath, Somerset, England, Zone VIIb	6,044±380
347	Peat, Shapwick Heath, Somerset, England, Zone VIII	3,099±250
		3,520±300
	Ave.	3,310±200
349	Gyttja, Hockham Mere, Norfolk, England, 790-825 cm., Zones II-III	6,619±380
		6,491±420
	Ave.	6,555±280

APPENDIX (*Continued*)

Number	*Description*	*Date (years before A.D. 1950)*
353	Birch wood, Mesolithic platform, Star Carr, Seamer, Yorkshire, England, Zone IV	10,167±560
		8,808±490
	Ave.	9,488±350
355	Gyttja, Knocknacran, Co. Monaghan, Ireland, Zone II	11,310±720
358	Peat, Clonsast, Co. Offaly, Ireland, Zone VI	5,824±300
363	Cypress stump, Santee River, S. C.	>17,000
364	Oak wood from lacustrine beach, Dolton, Ill.	3,469±230
365	Spruce root, Two Creeks horizon, Manitowoc Co., Wis.	11,437±770
366	Peat in which no. 365 was rooted	11,097±600
385	Wood from outwash, Bonfils, Mo.	12,148±700
417	Lower peat, Boylston St. fishweir site, Boston, Mass.	5,717±500
418	Marine silt, Boylston St. fishweir site, Boston, Mass.	3,851±390
419	Wood from Mankato drift, Appleton, Wis.	5,938±300
		6,864±300
	Ave.	6,401±230
428	Sandals, Fort Rock Cave, Ore.	9,188±480
		8,916±540
	Ave.	9,053±350
432	Pine cones, Aamosen, Sjaelland, Zone V ..	7,583±380
433	Hazel nuts, Mesolithic summer house, Aamosen, Sjaelland, Zone VI	9,935±440
		9,927±330
	Ave.	9,929±350
434	Charcoal from same summer house as no. 433	8,631±540
438	Peat from alluvium near Bridgeville, Pa. ...	>16,000
444	Gyttja, Neasham, near Darlington, Northumberland, England, Zone II	10,851±630
450	Peat, 0-2 cm. below *Grenzhorizont*, Melbeck, Hannover, Germany	1,446±250
		1,452±290
	Ave.	1,449±200

APPENDIX (*Continued*)

Number	*Description*	*Date (years before A.D. 1950)*
462	Charred wood, Neolithic "A," Edenside Tarn, Cumberland, England	4,964±300
465	Wood from Tazewell or Cary drift, Oxford, Ohio	>15,000
466	Wood from Illinoian till, Vermilion Co., Ill.	>17,000
470	Charcoal from alluvium, Frontier Co., Neb.	10,493±1,500
471	Charcoal from alluvium, Frontier Co., Neb.	9,880±670
		9,167±600
	Ave.	9,524±450
475	Lacustrine mud from middle organic horizon, Singletary Lake, N. C.	>20,000
476	Lacustrine mud from lower organic horizon, Singletary Lake, N. C.	>20,000
479	Plant debris, Lea Valley arctic horizon, Ponders End, England	>20,000
480	Oak wood, last interglacial stage, Cambridge, England	>17,000
481	Wood from loess underlying Cary till, Polk Co., Ia.	>17,000
484	Dung of ground sloth, Mylodon Cave, Ultima Esperanza, Chile	10,800±570
		10,864±720
	Ave.	10,832±400
485	Burned bone of sloth, horse, and guanaco, Palli Aike Cave, Chile	8,639±450
496	Wood from beneath Mankato drift, Bronson, Minn.	>19,000
497	Wood from Lake Agassiz sediments, Moorhead, Minn.	11,283±700
504	Peat, Sand Island, Bayfield Co., Wis.	3,656±640
508	Wood from Cary till, Montgomery Co., Ohio	>17,000
510	Wood from Farmdale loess, Farm Creek, Ill.	>20,000
511	Charcoal, Cochise culture, Sulphur Spring stage, Ariz.	6,210±450
515	Charcoal, Cochise culture, Chiricahua stage, Ariz.	4,006±270
519	Charcoal, Cochise culture, San Pedro stage, Ariz.	2,463±310

APPENDIX (*Continued*)

Number	*Description*	*Date (years before A.D. 1950)*
536	Spruce wood, Two Creeks horizon, Manitowoc Co., Wis.	12,168±1,500
537	Peat, Two Creeks horizon, Manitowoc Co., Wis.	11,442±640
575	Wood from Lake Kickapoo sediments (Tazewell), La Salle, Ill.	>17,000

NOTES ADDED IN PROOF

1. A sample of burned bone (no. 558) from Lubbock, Texas, associated with Folsom man, gives a date of 9,883±350 years.

2. A sample of gyttja (no. 478) from Upper Linsley Pond, Conn., was taken in March, 1950, at 10.55 m. in the center of the lake by means of the specially constructed large sampler. A new pollen diagram at the site shows the horizon of the sample to be middle C1, and its radiocarbon age is 8,794±550 years, slightly older instead of slightly younger than no. 39. Because of the way it was collected, the new sample indicates that the pine zone in Connecticut is about 9,000 instead of about 8,000 years old.

3. A sample of peat (no. 500) from Lake Cicott Bog, Cass County, Indiana, taken at 22 to 23 feet at the top of the pine zone, gives the age of 5,625±310 years. The validity of this composite sample has been discussed at length by Deevey and Potzger (1951), and its incredibly low radiocarbon age may perhaps be attributed to unconformities in the sediments, of which there is no trace in the pollen diagrams. In view of the elaborate and unsuccessful attempt to circumvent it by statistical analysis, such a difficulty may be regarded as inherent in the method of multiple sampling.

4. A sample of birch wood (no. 435) from another summer house in the same area and at the same horizon as nos. 433 and 434 is dated as 9,425±470 years old, thus confirming the less reasonable of the two discordant dates, and reinforcing the suggestion of stratigraphic confusion by human occupation of the site.

5. Sample no. 449, representing a layer two cm. thick immediately above the *Grenzhorizont* at the same locality, is dated as 1,129±115 years old, and is fully consistent with the result for no. 450.

6. The sample (no. 474) from the lower part of the uppermost organic horizon in Singletary Lake, N. C., gives the date of 10,224±510 years. This is a composite sample and must be regarded with suspicion, but its age agrees precisely with its stratigraphic position as inferred by Frey, in that it is younger than the Mankato maximum and older than the oldest pine-zone sample yet dated (no. 336).

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COMMENTS ON RADIOCARBON DATING FOR SAMPLES FROM THE BRITISH ISLES

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ABSTRACT. Results of radiocarbon assay of several samples from the British Isles are in general agreement with expectation, in that the dates fall in order of stratigraphic position as currently understood. One Irish and two English samples from pollen zone II (the Alleröd horizon) range from 9,861 to 11,310 years and thus confirm previous estimates of the age of this important time-marker; a fourth sample gave a seriously discordant figure, possibly because the method by which it was collected was faulty. Samples from two older horizons, the Ponder's End glacial substage and the interglacial deposits at Cambridge, gave minimum ages only. Six postglacial samples have also been dated; one accords closely with expectation, while the dates for the others suggest discrepancies of about 1,000 years. The method will undoubtedly prove of very great value in Quaternary research, but as it is subject to erors that are not yet understood, the few results so far obtained do not compel a revision of the accepted chronology.

THE estimated age of the British samples depends upon a nexus of evidence of late Quaternary history: in particular, the pollen zonation employed by Jessen for Ireland (Jessen, 1949) and by Godwin for England and Wales (Godwin, 1940). This pollen zonation is thought to be parallel to that of western South Scandinavia and northwest Germany, and has been related to absolute chronology by linkage to varve chronology at the early end of the scale and to archaeological datings at the more recent end.

Stratigraphic evidence of changes in climate, ocean level, fauna and flora have assisted in coordination of the basic correlation scheme of late Quaternary history, which is still naturally very imperfect.

The submitted samples will be considered in order of estimated age, the oldest first.

(1) *Interglacial* (sample 480 : C-14 dating . . . at least 17,000 years).—Oak timber collected from sepia-coloured organic muds in sewer trench excavations of 1949, at Histon Road, Cambridge, is known to be part of an interglacial deposit on grounds of contained fauna and flora, as well as sequence of river terraces. Pollen analyses indicate probability that the deposit represents part of the last interglacial period at about the time of maximum extension of the Eem sea. (Hollingworth, Allison and Godwin, 1950).

It would be expected that material from the last interglacial would be far beyond reach of the present C-14 assay technique.

(2) *Glacial* (Late Glacial in a wide sense). (Sample 479 : C-14 dating . . . older than 20,000 years). Plant debris sifted from silty material of frozen rafts incorporated in coarse gravel at Nazeing, Lea Valley, north of London. This bed is the "Ponder's End" stage encountered at many sites in the Lea Valley, associated with a characteristic flora of Arctic willows and other species, a characteristic molluscan fauna and remains of *Elephas primigenius*, *Rhinoceros tichorhinus*, and *Dicrostonyx henselii*, etc. (Warren, *et al.*, 1912, 1915, 1923).

Recent unpublished work on fauna and flora of overlying peats prove these to be Late Glacial in the modern restricted usage (see below) and hence the Ponder's End stage is very likely to date some time back into the last glaciation: the assay of more than 20,000 years is conformable with this view.

(3) *Late Glacial* (in restricted sense). The close of the Late Glacial in Scandinavia is set at the stage of commencing ice-withdrawal from the middle Swedish end moraines (beginning of the Fini-glacial) and is dated by varve chronology at c. 10,000 years. The Late Glacial in this sense is divided into two cold periods, pollen Zones I and III, by an intervening mild period (the Alleröd oscillation) of Zone II. Zone III is succeeded by the final postglacial climatic amelioration of Zone IV. Zones II and III are thought to have occupied jointly some 2,000 years: thus the Alleröd mild phase itself may be given roughly an age of 11,000 to 12,000 years (Jessen, 1949).

Sample 341: C-14 dating . . . 9861 ± 500. Samples from exposed profiles in Kaolin pit at Hawks Tor, Cornwall, collected in Sept. 1949. Here a lower peat bed (Zone II) underlies a gravelly solifluction soil of Zone III containing a cold-indicating flora. The sample is from moss-sedge peat of middle Zone II. (Conolly, Godwin and Megaw, 1950).

Sample 444 : C-14 dating . . . 10,851 ± 630. Dr. K. M. Blackburn collected this sample of organic mud from Zone II in an exposed profile at Neasham, near Darlington (Northumberland). Deposits were examined for stratigraphy, pollen and macrofossil plant content by Dr. Blackburn and Mr.

G. F. Mitchell, and are vouched for as a fine and typical Alleröd deposit in the region of the New Drift of the last main glaciation.

Sample 355 : C-14 dating . . . 11,310 ± 720. Mr. G. F. Mitchell collected this sample of lake mud of Zone II at Knocknacran, Co. Monaghan, Ireland. Mitchell's own work on stratigraphy and vegetational history at this site conforms directly with Jessen's in other parts of Ireland (Jessen, 1949).

Sample 349 : C-14 dating . . . 6619 ± 380 / 6491 ± 420 This was collected by Hiller peat sampler from a depth of 790-825 cm. at borehole D.B.5, at Nockham Mere, Norfolk, and consists of calcareous silty nekron-mud (openwater lake mud). It is referred to Zones II and III on grounds of pollen zonation (see Godwin 1944 and unpublished material).

The three samples 341, 444, and 355, all undoubtedly referable to Zone II, (like the German sample from Wallensen im Hils: C-14 dating 11,044 ± 500), give C-14 assay results conforming very well with expectation. They collectively compare well in age with the American samples of wood and peat from Two Creeks Forest Bed, Manitowoc Co., Wisconsin: this may indicate a possible transatlantic climatic correlation of Two Creeks with the Alleröd stage.

Sample 349 gives a large discrepancy from expectation of a nature that might be caused by later incorporation of younger more active C from above. It is possible that this could have happened by fault in the sampling technique for repeated borings were necessary, close together, to obtain the bulk required, and it is possible that material from upper layers may have got into the earlier boreholes and then was picked up in later samples. It seems unlikely, in view of the striking regularity of the pollen curves, that there can be *gross* mixing of organic layers in the lake, but motile anaerobic bacteria seem to be present in the gel-muds and might transfer active C to lower layers. Deevey in samples 119-122 has found big errors in the C-14 assay of lake-mud samples collected by this same 'multiple shot' technique.

(4) *Early Postglacial* (Sample 340 : C-14 dating . . . 8011 ± 400 / 8540 ± 780). Above the solifluction earth of Zone III, at

Hawks Tor, Cornwall, lies an upper peat-bed formed through a large part of the postglacial period. Samples were taken in Sept. 1949 from exposures at the base, which was estimated from the pollen sequence to fall early in Zone IV. The C-14 assay appears to be at least 1,000 years too young. The error might possibly lie in our failure to recognize unconformity in the sequence above the gravelly soil of Zone III, possibly in later incorporation of younger more active C (Conolly, Godwin and Megaw, 1950.)

(5) *End of Zone IV: immediately before Boreal period.* (Sample 353 : C-14 dating . . . 9488 ± 350). This sample is of substantial branches of *Betula* wood forming part of a wooden platform in a rich early Mesolithic occupation site at Star Carr, Seamer, Yorks., investigated in 1949 and 1950 by Cambridge University parties (Clark *et al.*, 1949). Pollen analyses and stratigraphic examination show that the former Lake Pickering existed through late glacial and postglacial time, and the rich archaeological material is stratified into the lake muds immediately below the horizon where the rising curves for pollen of *Quercus*, *Ulmus* and *Corylus* indicate the opening of Zone V. The C-14 assay accords closely with expectation.

(6) *Boreal period.* (Sample 358 : C-14 dating . . . 5824 ± 300). This peat sample was collected from the great raised bog system at Clonsast, Co., Offaly, Ireland, by Mr. G. F. Mitchell who has worked on its stratigraphy and pollen-zoned its layers. Mr. Mitchell writes that the sample was cut directly from an open face in the bog. Pollen samples collected at the same time proved remarkably barren, but on stratigraphical grounds the sample may be assigned to the very end of the Boreal Period (late VIc), or perhaps to the Boreal/Atlantic transition. The apparent discrepancy might thus be reduced; if the sample were actually from Zone VIc the expected age would be c. 8,500 years.

(7) *Atlantic Period.* (Sample 343 : C-14 dating . . . 6044 ± 380). One sample was collected by excavation from humified *Sphagnum-Calluna* peat of the raised bog of Shapwick Heath, Somerset. Pollen samples were not examined at the precise sampling site but the bog stratigraphy is consistent and well understood. Taken substantially below the level of a Late

Bronze Age trackway, where *Cladium-Phragmites* peat has just given place to oligotrophic peat formation: this is early in pollen Zone VIIb, which possibly commences at about 5000 years. The C-14 assay is at least 1000 years too old, but the estimate of age of the pollen zone boundary is insecure (Clapham and Godwin, 1948; Godwin, 1948).

(8) *Neolithic "A"* (Sample 462 : C-14 dating . . . 4964 ± 300). "Piece of charred wood from lakeside settlement at Ehenside Tarn, Cumberland", submitted by J. W. Brailsford, British Museum. The wood is not necessarily contemporaneous with the culture but will not be greatly different in age. Estimated age is about 4000 years. The C-14 assay is perhaps 1000 years too great, but uncertainty of provenance makes conclusions somewhat unsafe.

(9) *Zone VIII* (Sample 347 : C-14 dating . . . 3099 ± 250
3520 ± 300).
This sample was collected near Decoy Pool Wood, Shapwick Heath, Somerset, by excavation, and is moderately humified *Sphagnum-Calluna* peat which overlies peat of a major flooding episode of Early Iron Age date (Godwin, 1948). It is definitely below the late Romano-British occupation surface of the bog. Thus its age may be estimated at 2000 years with a maximum error of 300 years either way. The C-14 assay is thus at least 1000 years too great. Since these samples were taken not far below the present dried surface of the bog, which is tree grown, there is some possibility of downward penetration of recent roots having *raised* the Carbon activity of the layer sampled, but I see no possible explanation for the result in the opposite sense.

[The flooding horizon referred to above corresponds in date with the peat over the *Grenzhorizont*. This phenomenon is represented by sample 450 from N.-W. Germany. (C-14 dating . . . 1446 ± 250, 1452 ± 290), which comes from the dry Sub-Boreal layers beneath the flooding surfaces of the Early Iron Age. This sample cannot be less than 2500 years old: thus the C-14 assay figures are 1000 years too young.]

GENERAL COMMENT

The C-14 datings for the older samples are in general of the expected age. The method already seems to have confirmed that the varves of de Geer are indeed annual deposits, a mat-

ter which has been in dispute. The results do not cast in doubt the accepted postglacial chronology as a whole.

It is clear that large unknown sources of error remain and multiple-shot sampling in deep lake muds appears suspect.

Too *young* an age can clearly be caused by secondary incorporation of more recent organic matter into old deposits, as by growing roots, burrowing animals, moving water or bacterial activity. We are rather ignorant of the hydrology of raised bogs: the old humified *Sphagnum* peat is certainly impermeable and it is possible that drainage channels or surfaces may carry colloidal humic material into layers of greater or less age.

Too *great* an age may result from introduction of inactive Carbon, as with bicarbonate derived from ancient limestones, brought into a lake, where it is fixed in organic compounds or precipitated through biological activities.

A priori one would expect the cellulose or lignin skeletons of plants to provide the best material (a suggestion strengthened by the very conformable results of analysing timber of *Sequoia*, etc.). Nevertheless it is to be noted that Troels-Smith's samples from Aamosen show a big difference between the C-14 assay of charcoal on the one hand and hazelnuts on the other—about 1300 years.

If these errors can be understood and eliminated the method will undoubtedly prove of very great value in Quaternary Research: not only by itself providing an absolute chronology, but by checking other systems of relative dating so that they can transmit absolute dating.

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THE OCCURRENCE OF CHRYSOBERYL AT GREENFIELD, NEW YORK

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ABSTRACT. A report of the rediscovery of a chrysoberyl locality in the town of Greenfield, Saratoga County, New York, including the history and occurrence of the locality and the mineral associations, is presented.

HISTORY

THE occurrence of chrysoberyl in the town of Greenfield, Saratoga County, New York, was first noted by Steel in a letter to Benjamin Silliman dated July 29, 1821. The letter was published in THE AMERICAN JOURNAL OF SCIENCE AND ARTS (1822, pp. 37-38). Steel wrote, in part, " I hasten to inform you of the discovery of a new locality of chrysoberyl and prismatic mica, presuming that, as these minerals have not occurred very frequently in the United States it may afford you some gratification. They are found in a vein of granite which passes through gneiss; the vein was discovered some years ago. The rock in which this vein is situated, is about one mile north of the high rock springs at Saratoga."

Troost (1824), in a paper read before the Philadelphia Academy of Science, referred to Steel's letter and described the occurrence: "These crystals are imbedded in a granite rock which is the pegmatite subordinate to the gneiss. This rock includes besides the chysoberyl, the black tourmaline, beryl, and garnet."

Beck (1842), in his *Mineralogy of New York*, wrote, "The only locality of chrysoberyl at present known in this state, is in the town of Greenfield, about a mile north of the village of Saratoga Springs. It occurs in a vein of granite transversing gneiss, and is associated with tourmaline, garnet, apatite, feldspar, and mica. Its colour is usually a yellowish green."

Beck (1845) gives the last recorded visit to the locality when he noted that "large fine specimens have been obtained at the Greenfield locality in 1845 by Dr. Leonard of Lansingburgh." Thus so far as can be determined, the exact location of this occurrence has been lost since that time.

Recently, the authors had occasion to make a field study of the crystalline rocks of this area, and in so doing, found what they believe to be the original chrysoberyl locality.

LOCATION

The Greenfield locality is slightly less than a mile north of the Saratoga Springs city line (fig. 1), and can be reached by going north from Saratoga Springs on U. S. Route 9 for a mile and a half beyond the Delaware and Hudson Railroad crossing, turning west on town highway three (St. Clement's Road) and proceeding for half a mile. The dike is about 40 yards north of the road and west of a small pond on here many decades, perhaps nearly a century, ago.

GEOLOGY

The local bedrock is part of the pre-Cambrian crystalline complex which makes up the Adirondack area, and consists of gneisses which crop out in a series of ridges whose east-west

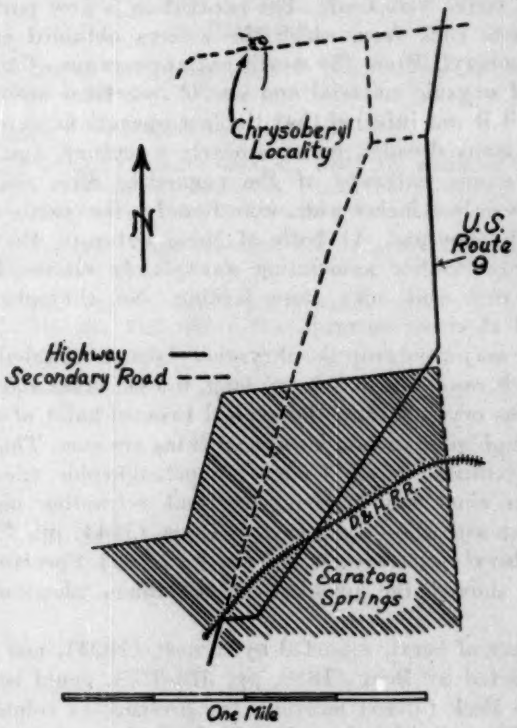

Figure 1. Location map.

trend is probably due to the direction of the lineation, rather than to any other cause. The ridges have been rounded and polished by glaciation and many of the depressions between them, now floored with glacial debris, contain small streams or swamps.

The chrysoberyl which occurs in a pegmatite stringer perhaps 2 feet wide cutting gneiss, is intimately associated with quartz, plagioclase, orthoclase, black tourmaline, garnet, biotite and muscovite.

The present major outcrop of the chrysoberyl-bearing pegmatite is in an excavation following the trend of the dike, which strikes north 30° west and dips 70°-75° to the northeast. The pegmatite has been removed to a depth of 8 feet for 45 feet along the strike, exposing the western contact of the dike and the enclosing gneiss along which the above measurements of dip and strike were made. The excavation is now partly filled with waste rock from which the writers obtained specimens of chrysoberyl. From the weathered appearance of the rocks, depth of organic material and size of two trees now growing in the pit it was inferred that the last operations were carried on here many decades, perhaps nearly a century, ago.

Two minor outcrops of the pegmatite dike, reduced to stringers only 3 inches wide, were found a few yards south of the main exposure. At both of these outcrops the quartz-feldspar-tourmaline association was plainly visible; however, both garnet and mica were lacking. No chrysoberyl was observed at either outcrop.

At the major outcrop the chrysoberyl occurs as tabular crystals which range up to 1.2 cm. long, 0.5 cm. wide and 0.5 cm. thick. The crystals show the typical twinned habit of the mineral, though good pseudo-hexagonal twins are rare. The color is a light yellowish-green. Under the petrographic microscope, specimens show low birefringence and refractive indices in agreement with those indicated in Dana (1944, pp. 718-722) (Chrysoberyl: α=1.746; β=1.748; γ=1.756). Spectrographic analysis showed the presence of beryllium, aluminum, and silicon.

No trace of beryl, reported by Troost (1824), nor of apatite, reported by Beck (1842, pp. 375-377), could be found. Although Beck (1845) mentions the presence of columbite at this locality, none has been identified by the present authors.

The Wheatley Collection at Union College contains a number of excellent specimens of chrysoberyl in the matrix collected from this locality during the early part of the last century, and among them is one identified as columbite. Study of these specimens failed to reveal any evidence of apatite or beryl.

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FROST-HEAVED TUSSOCKS IN MASSACHUSETTS*

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ABSTRACT. The height of tussocks of some grasses and sedges in lowland areas of northeastern United States is increased by frost-heaving processes similar to those that affect some tussocks in tundra regions of Alaska.

INTRODUCTION

TUSSOCKS of *Carex* cf. *stricta* and *Calmagrostis* sp., formed in part by differential frost-heaving, are common in fresh-water marshes of eastern Massachusetts and were studied in Belmont township (fig. 1). The tussocks are similar in form and origin to tussocks studied by the writers on Seward Peninsula, Alaska (Hopkins and Sigafoos, in press).

The tussock is a plant form characteristic of certain grasses and sedges that grow as matted, isolated tufts in mineral or highly organic wet soils. It consists of a ball-like mass of living and dead plant parts that stands as a small mound or hummock above the ground surface. Tussocks are common features in tundra regions, where they are found on broad, poorly drained hilltops, on wet slopes as steep as 10°, and on marshy lowland areas. In forested regions, tussocks are confined to marshes. In New England tussocks are common in marshes where only a thin layer of peat is present.

Most tussocks found in the tundra regions of northwestern Alaska are products of the interaction of plant growth and frost action. There, mature tussocks of *Eriophorum vaginatum* ssp. *spissum* owe most of their height to differential frost-heaving. Tussocks of *Calmagrostis*, in both Alaska and Massachusetts, acquire most of their height by growth of the plant, but frost-heaving increases the height of some. Tussocks formed by certain species of *Carex* in northwestern Alaska originate in a fashion similar to those formed by E. *vaginatum* ssp. *spissum*.

The *Carex* tussocks studied in Massachusetts owe most of their height to differential frost-heaving, and are a type of cryopedologic surface feature (microrelief feature formed by intensive frost action). The *Calmagrostis* tussocks result chiefly

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Plate 1A. Side of burned sedge tussock. Stone embedded in side of tussock above pocketknife. Note road-leaved jewelweed seedlings and undisturbed litter around tussock.

Plate 1B. Alder shrub rooted level with base of sedge tussocks. Hunting knife by tussock in left foreground gives scale.

Plate 2A. View of sedge tussock.

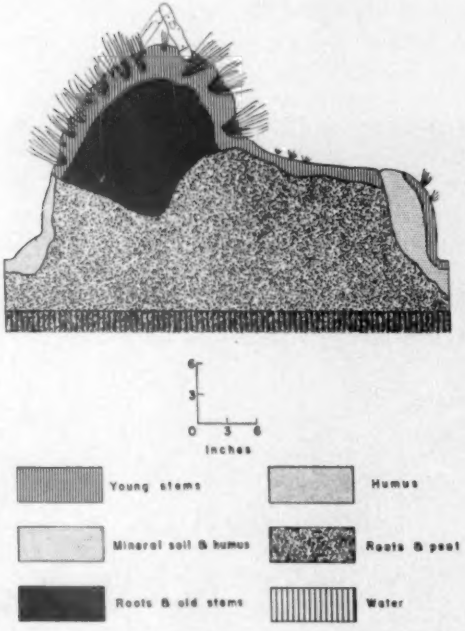

Plate 2B. Section through the tussock. About one-half of height consists of roots in a mound of peat.

from plant growth, but a few tussocks have been heaved slightly.

Several other types of active cryopedologic surface features in New England have been reported. Antevs (1932, pp. 49-61) and Goldthwaite (1940, pp. 39-41) described active turf-banked terraces and miniature stone nets and stripes on Mount Washington, New Hampshire, at altitudes above 4,500 feet. Antevs reported similar features on Mount Katahdin, Maine. Denny (1940) described active miniature nets and stripes on Mount Monadnock, Mount Cardigan, and Mount Kearsarge, New Hampshire, at altitudes ranging from 2,880 to 3,150 feet. Nichols and Nichols (1936) and Butler and Ray (1946) found active nets and stripes in exceptionally favorable sites on Mount Desert Island, Maine, at altitudes of 1,025 to 1,300 feet.

TUSSOCKS IN BELMONT, MASSACHUSETTS

Tussocks were studied in a small marsh (plate 1B) beside State Highway 2 in Belmont, Mass., about 10 miles northeast of Boston, at an altitude of about 240 feet (fig. 1). The marsh

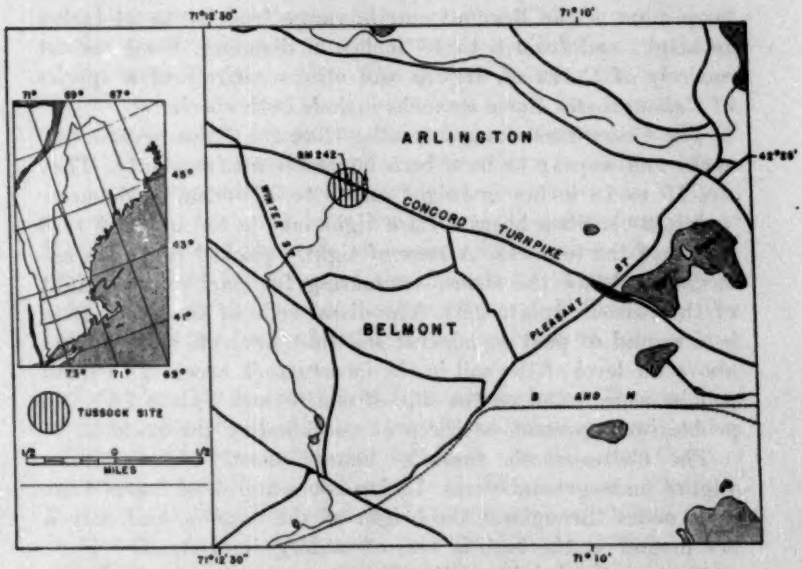

Fig. 1. Index map showing tussock site at Belmont, Mass. (from U. S. G. S. map of Lexington, Mass., quadrangle, 1946).

is in a shallow valley, walled by rounded, till-covered bedrock knolls. It is drained by a small meandering stream that flows against the base of a hill at the west edge of the marsh. The surface of the marsh is covered with a layer of peat 6 to 12 inches thick that overlies gravelly mineral soil. Water was standing in low areas away from the stream in May 1949, when the study was made.

Species of *Carex* and *Calmagrostis* are prominent in open areas in the marsh (plate 1B). Tall shrubs of *Alnus* (alder) and low shrubs of *Spirea tomentosa* (spirea) are common. Seedlings of *Impatiens biflora* (jewelweed) were abundant at the time of the investigation. A young stand of elm, red maple, and willow is present in the marsh away from the stream, where *Caltha palustris* (cowslip, marsh marigold) and *Symplocarpus foetidus* (skunk cabbage) are common on the wetter sites. The dead vegetation had been burned over a few weeks before the study was undertaken. Many other swamps with tussocks along the highway had been burned during the same period.

The tussocks, spaced at intervals of 6 to 10 feet over a large part of the Belmont marsh, range from 10 to 24 inches in height and from 8 to 15 inches in diameter. Some consist entirely of *Carex* cf. *stricta* and others entirely of a species of *Calmagrostis*. Some tussocks include both species.

The *Carex* tussocks are smaller than the *Calmagrostis* tussocks and appear to have been burned more frequently. They are 10 to 18 inches in height and 8 to 12 inches in diameter (plate 2A). Stem bases form a tight mat in the upper 2 to 5 inches of the tussocks. A zone of tightly packed roots lies immediately below the stems, accounting for part of the height of the tussock (plate 2B). The distal ends of the roots grow in a mound of peat or mineral soil that projects a few inches above the level of the soil in the intertussock areas. Two small pebbles were found on the side of one tussock (plate 1A). No pebbles were present on the peat surrounding the tussock.

The *Calmagrostis* tussocks consist mostly of vertically aligned underground stems. Living roots and dead leaves arise from nodes throughout the height of the tussock, and only a low mound at the base is free of underground stems.

Most of the height of the *Calmagrostis* tussocks is due to the growth of the stems; however, the *Carex* tussocks of Massa-

chusetts, like the *Eriophorum* tussocks of Seward Peninsula, owe their height to some process other than growth of the plant. The stems, which are the only part that can increase the height of the plant by growth, account for only a part of the height of the tussocks. Several hypotheses might explain the remaining height: 1) the soil surrounding the tussocks might have been removed by stream erosion or might have been trampled by grazing animals; 2) the tussock-forming plants might have taken root on pre-existing mounds formed by burrowing animals or by the overturning of trees (Lutz and Griswold, 1939); 3) the stems might have started at a lower level and were pushed upward to their present position by frost-heaving.

Some parts of the tussock area lie above ordinary flood stages of the stream, as indicated by the lack of rill markings and the presence of an unbroken, undisturbed cover of small grasses between the tussocks. Nearby marshes with tussocks lie in closed depressions from which no material could be exported by stream erosion. The Belmont marsh is fenced and there are no indications that livestock has been present for several years. A few large alders more than 15 years old grow in the marsh and are rooted at the same level as the bases of the tussocks (plate 1B). The surface between the tussocks, therefore, has stood at its present level for a few decades; the tussocks were not formed by trampling or by removal of soil.

Anthills have never been seen by the writers in marshy areas. No burrowing animals were seen in the tussocks, nor is there any evidence that any have lived there. The close spacing of the tussocks and the lack of modern deadfalls in the swamp argues against formation of the mounds by the uprooting of trees. None of the tussocks examined grew on boulders. The tussocks are not believed to have been initiated on pre-existing mounds.

Frost-heaving is capable of forming tussocks. Observations on Seward Peninsula, Alaska, indicate that the tops and centers of tussocks freeze later in the fall than the sides and the surrounding mineral soil, peat, and turf (Hopkins and Sigafoos, in press). During the freezing of the wet soil, additional water is absorbed to form lenses of clear ice (Taber, 1930). Thus, after the soil is frozen, the quantity of ice present greatly exceeds the natural porosity of the unfrozen soil. The freez-

ing mineral soil between the tussocks expands and moves laterally into the unfrozen zone beneath the tussocks, as well as upward. Repeated cycles of frost-thrusting from the intertussock areas raise a small mound of mineral soil beneath the tussock and force the proximal portions of the roots vertically out of the soil. The tight, matted growth of the stems prevents the plant from being torn during the heaving. Tussocks of *Carex* cf. *stricta* in the Belmont marsh are largely products of these processes.

CONCLUSIONS

The forms of some plants and the microdistribution of many in temperate, subarctic, and arctic regions are affected by intensive frost action. It is probable that frost action in soil is effective in modifying the upland environment as well as the swamp environment in temperate regions; consequently, the distribution of plants is altered by this process. Frost action is most effective in bare soil, especially if the soil is wet, and thus is an inhibiting factor in the growth of seedlings in early successional stages.

In tundra regions, perennially frozen ground at shallow depth impedes subsurface drainage and maintains wet conditions in the soil throughout the growing season. Sigafoos (1949) has shown that frost action under these conditions is the dominant environmental factor controlling the microdistribution of plants. In temperate regions similar conditions exist in fresh-water marshes, resulting in tundra-like plant forms.

Many microrelief features in middle latitudes may be due to present day frost action; studies of land forms and vegetation should include a consideration of the effect of varying intensities of frost action in the past and the present. Bogs and marshes in temperate regions at low altitudes are exceptionally favorable places in which to look for cryopedologic surface features because they are among the closest analogues of arctic and subarctic tundra. Poor drainage maintains a high moisture content in the marsh soil throughout the critical autumn freezing cycle, thus permitting a maximum of frost-heaving. Cold air drainage from adjoining slopes during cold, clear nights results in lower minimum temperatures in the bogs and thus in more numerous and sharper cycles of freezing and thawing

than in adjoining uplands (Wolfe, Wareham, and Scofield, 1949). In arctic and subarctic regions, climatic conditions and the presence of perennially frozen ground at shallow depth maintains similar moisture conditions, not only in lowlands, but also on slopes and hilltops. Consequently, cryopedologic surface features such as tussocks are much more widespread.

ACKNOWLEDGMENTS

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WASHINGTON, D. C.

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A BISON FROM EASTERN WASHINGTON

H. W. TIPPER, Z. V. JIZBA, AND R. L. KONIZESKI

ABSTRACT. A bison skull from Whitman County, Washington has been identified as the skull of *Bison* (*B.*) *bison bison*. This specimen is the first of this species to be described from Washington and indicates that the living plains bison was present in eastern Washington in prehistoric time. The age of this specimen is not known conclusively but invertebrate fossils occurring with the skull are possibly late Pleistocene.

IN November 1949 a small collection of fossils was obtained from Sec. 25, T 15 N, R 38 E in Whitman County, Washington. This locality is along Willow Creek near a point on State Highway No. 11B eight miles east of Hooper (fig. 1). The collection included the skull of a bison, several fragments of other vertebrates, and several genera of invertebrates. The invertebrates were identified by Dr. Teng-Chien Yen, Washington, D. C., and the two vertebrate genera listed were identified by the writers. The measurements of the bison skull were made in conformance with the system proposed by Skinner and Kaisen (1947, pp. 142-148).

The fossils occurred in a poorly stratified, unconsolidated, valley-fill deposit of light-gray sandy silt most of which appears to be reworked Palouse Soil. This material has accumulated to a thickness of at least 30 feet for an undetermined distance along the valley. Recent downcutting of Willow Creek has resulted in steep, high bank exposures of the valley-fill material. The fossils, both vertebrate and invertebrate are exposed in the faces of these cliffs, mainly along a zone which is uniformly 10 to 15 feet above the streambed. The bison skull occurred approximately 200 yards upstream from the main invertebrate locality.

These exposures are immediately downstream from the intersection of Willow Creek and a large remnant of sands and gravels of definite Pleistocene age. Vertebrate remains have been collected from this same locality over a period of at least ten years.

The writers' collections include:

Vertebrates

Bison (*Bison*) *bison bison* (Linnaeus)
Taxidea taxus neglecta Mearns
Several fragments of small rodents

Invertebrates

Gyraulus cf. *G. vermicularis* (Gould)
Lymnaea palustris buttoni (Baker)
Lymaea palustris nuttaliana (Lea)
Lymnaea humilis Say
Succinea avara (Say)
Orehelix strigosa depressa (Cockerell)

With regard to the invertebrates, Yen comments: "The species contained in this lot are represented in the Recent fauna, distributed further south and east from the present fossil site. *Succinea avara* has been recorded from several Pleistocene deposits. It is highly possible that these fossil species are of late Pleistocene age."[1]

The bison skull is well preserved. The left horn-core, from 2 inches above the burr to the tip, is missing and the tip of the right horn-core is broken but was recovered with the skull. The anterior margin of the nasal bone is slightly broken and the fragments missing. M^1, M^2, and M^3, left and right, and the left P^4 are present but all other teeth are missing.

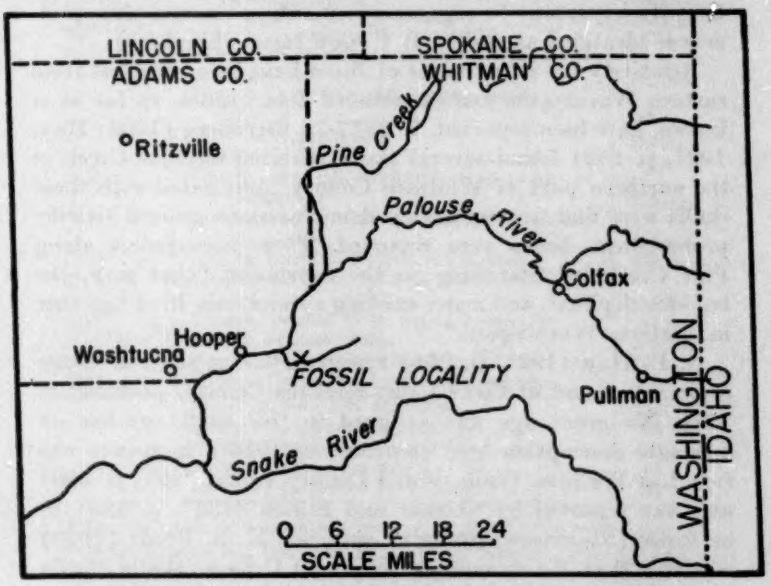

Fig 1. Map of part of eastern Washington showing fossil locality.

[1] Written communication.

The skull configuration and the teeth indicate that the skull is that of a male *Bison* which had reached early maturity. The measurements (table 1), with the exception of measurement no. 11, fall within the limits established for *Bison (Bison) bison bison* (Skinner and Kaisen, 1947, p. 162). Half the measurements used for comparison are very near the average measurements for this species and several of the remainder fall well below the average, but the measurements most closely approximate those of this species and do not closely agree with the measurements of any other species or subspecies.

By comparing the parts of this specimen with illustrations of other individuals of this species, several differences are noted. The horns of this specimen are depressed, do not rise above the top of the cranium, and do not curve posteriorly as strongly as most illustrations of this species would indicate. The orbits protrude very strongly, probably more than would be expected of an early mature specimen. However, the differences and variations that have been noted are not sufficiently important to suggest a new subspecies and this specimen is identified as *Bison* (*B.*) *bison bison* (Linnaeus).

Relatively few occurrences of *Bison* have been recorded from eastern Washington and no detailed descriptions, so far as is known, have been reported. In 1877-78 Sternberg (1903; Hay, 1927, p. 252) found several skulls of bison on Pine Creek in the northern part of Whitman County. Associated with these skulls were flint arrowpoints and in this same general vicinity proboscidean bones were reported. These occurrences along Pine Creek led Sternberg to the conclusion "that man, the buffalo, elephant, and many existing species once lived together in eastern Washington."

O. P. Hay (1927, p. 254) reported that a skull of *Bison bison* was found at Clear Lake, Spokane County, probably in 1913. No great age was assigned to this skull nor has an adequate description been recorded. In 1916 a horn-core was found at Wallula, Walla Walla County (Hay, 1927, p. 250) and was reported by Skinner and Kaisen (1947, p. 180) to be *Bison* (*Simobison*) *antiquus antiquus*. H. S. Brode (1928) reported that the museum of Whitman College, Walla Walla had a large vertebra of a bison identified as *Bison latifrons*. The locality from which this was obtained was unknown but was believed to be in eastern Washington.

TABLE 1

Measurements of the skull of *Bison* (*B.*) *bison bison*

KEY NO.		
1	Spread of horn-cores, tip to tip	627 mm.*
2	Greatest spread of cores on outside curve	634 mm.*
3	Core length on upper curve, tip to burr	165 mm.
4	Core length on lower curve, tip to burr	194 mm.
5	Length, tip of core to upper base at burr	162 mm.
6	Vertical diameter of horn-core at right angle to longitudinal axis	71 mm.
7	Circumference of horn-core at right angle to longitudinal axis	236 mm.
8	Greatest width at auditory openings	262 mm.
9	Width of condyles	117 mm.
10**	Depth, occipital crest to top of foramen magnum	89 mm.
11	Depth, occipital crest to lower border of foramen magnum	133 mm.
12	Transverse diameter of core at right angle to longitudinal axis	74 mm.
13	Width between bases of horn-cores	186 mm.
14	Width of cranium between horn-cores and orbits	265 mm.
15	Greatest postorbital width	320 mm.
16**	Anterior orbital width at notch	260 mm.
17	Width of skull at masseteric processes above M^1	184 mm.
18	Rostral width at maxillary-premaxillary suture	108 mm.
19	P^2-M^2, alveolar length	145 mm.*
20	M^1-M^2, alveolar length	89 mm.
O-P	Length, over all, occipital crest to tip of premaxilla	502 mm.
F-P	Length, basilar, foramen magnum to tip of premaxilla	465 mm.
O-T	Length, occipital crest to tip of nasals	432 mm.*
O-N	Length, occipital crest to nasal-frontal suture	229 mm.
M-P	Length, beyond P^2 to tip of premaxilla	127 mm.
N-T**	Length of nasal bone	208 mm.*
21**	Angle of posterior divergence of horn-core	70°
22**	Angle of proximal horn-core depression	20°
	Index of horn-core curvature	120
	Index of horn-core compression	96
	Index of horn-core proportion	73
	Index of horn-core length	62
	Index of tooth-row proportion**	31*

* Less accurate measurements because of imperfect preservation.

** Measurements not listed by Skinner and Kaisen (1947, p. 162) and not used for identification of this specimen.

It is apparent that there are two localities in eastern Washington at which remains of modern types of *Bison* may have been found but there is no adequate record as to whether they were the living North American species, either the woodland bison, *Bison* (*B.*) *bison athabascae*, or the plains bison, *Bison* (*B.*) *bison bison*.

Bison (*B.*) *bison bison* has not been reported as living in Washington in historic times, but the finding of the skull herein described indicates that the species was present in eastern Washington in prehistoric times. This evidence serves to extend the range of this species west of the Continental Divide into Washington rather than confining the range to the Great Plains area as proposed by Skinner and Kaisen (1947, pp. 157-158).

The age of this specimen is not clearly indicated. Unquestionably it is prehistoric and Yen's statement regarding the age of the invertebrate fossils collected with the skull leaves open the possibility of a late Pleistocene age. Although the modern plains bison is believed to be a Recent species (Skinner and Kaisen, 1947, p. 157), it is not justifiable to assume a post-Pleistocene age for this specimen until the range of the plains bison is defined more definitely and until the Quaternary deposits of Washington have received further study.

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REVIEWS

The Geology of the Commonwealth of Australia; by the late Sir T. W. Edgeworth David, edited and much supplemented by W. R. Browne. In three volumes: Vol. I, pp. xx, 747, 58 pls., 209 figs.; Vol. II, pp. iv, 618, 26 pls., 168 figs.; Vol. III, maps in case. London and New York, 1950 (Edwin Arnold, £12, 12s, 0d; Longmans, Green & Co., $50.00).—These volumes provide a summary of virtually all that is known about the geology of Australia and form a fitting monument to the memory of the late Sir T. W. Edgeworth David, the great Australian geologist. Originally begun by Sir Edgeworth David, the work was left unfinished at his death in 1934, though two years before a Geological Map of Australia with a 177-page book of Explanatory Notes had been published. Thereafter it was carried forward by Dr. W. R. Browne, and though interrupted by the second World War has now been completed and published.

The work is in three volumes, but the third "volume" is a case containing a reprint of the Geological Map of Australia of 1932 and a new map of Australian New Guinea. Of the other volumes, the first summarizes the historical geology of Australia period by period, the second summarizes the physiography state by state and the economic geology raw material by raw material. Changes in interpretation or age assignment since the first publication of the Geological Map are indicated in the text, and a number of special maps cover areas little known in 1932. In the first volume Australian New Guinea receives a separate chapter, but in the second it is mentioned briefly only under gold, sulphur, phosphate, and petroleum.

Part I (Vol. I), Historical Geology.—The first impression made by the book is of authority. Though both the authors have been identified chiefly with New South Wales, they have spared no effort to make the work well balanced. They have called on their colleagues throughout the Commonwealth for aid on the subjects of their special knowledge, yet the material so gathered is so well assimilated that no discrepancies and inconsistencies appear and the treatment is uniform throughout. The volume is no collection of notes but a carefully thought out and diligently validated whole.

The second impression one gleans is that of almost overwhelming completeness. Apparently there is hardly a significant piece of work relating to the areal geology or geologic history of Australia that is not summarized here. Such virtue carries inevitably its own vices; there is so much material that the reader wishing merely a generalized knowledge of the geology of Australia finds the way difficult. A general chapter on tectonic history has been provided, but it concerns itself chiefly with the tectonic setting of the continent and with extra-Australian connections. Nevertheless all the material for synthesis is here, and the reader is counselled to take

heart and plunge into the apparently endless detail, map in hand, so that by his own efforts the trees will merge into a forest. For example, stratigraphers and for that matter all students of geologic history will find that out of the meticulous descriptions of the rocks of each of the Paleozoic systems as displayed in district after district through the eastern states will come a magnificent picture of the complex Tasman geosyncline, which lasted throughout the Paleozoic era though subjected in its various parts to not less than six major orogenies, all thought to have been accompanied by granitic intrusion. All the same, one wishes that Sir Edgeworth David or Dr. Browne had drawn that picture themselves in the thorough and authoritative manner that it deserves.

Many other interesting excursions await the American reader. He may smile at the vast lakes still postulated to account for virtually every non-marine deposit or recoil in horror on being solemnly told of glauconite casts of foraminifera belonging "to the Textulariidae, Globigerinidae, and (?) Rotaliidae" in the upper Precambrian rocks of Western Australia, but he may learn much from the discussions of arid physiography and soils, of duricrust and the superb Miocene peneplain, probably the finest on Earth, and from the well described evidences of ancient glaciations, in which Australia is nearly as rich as South Africa. The age of the late Paleozoic glaciations, for there seem to have been several spread over a considerable time, perhaps as much as a period, is discussed again, and also their paleogeographic implications, for though the northward movement of the ice in Australia is more orthodox than in South Africa or India, glaciation nevertheless reaches to 17½° south latitude. The "fascinating hypothesis of continental drift, which cuts the Gordian knot of so many geological problems" is referred to on this and other occasions, but is finally rejected because it fails "to interpret convincingly the known geological facts" (vol. I, pp. 688-689).

To conclude, despite the fantastic price, the volume must find a place in any library with any pretensions to completeness in regional geology. JOHN RODGERS

Part III (pages 145-593 of Vol. II), Economic Geology.—Since the first mine was opened in Australia in 1841 and the first gold discovered in 1851, the Commonwealth for 100 years has poured forth mineral treasures until it has become one of the great mineral-producing countries of the world. The present volume is a welcome one, for in its 450 pages is compressed most of the knowledge regarding the many and varied mineral deposits of this lonely continent. Like the other sections, this part represents a vast accumulation of information by many contributors.

The 15 chapters deal with 26 metallic ores and 37 nonmetallic

minerals and rocks, along with oil shale, petroleum, artesian water and ground water. These chapters are preceded by an introductory chapter on the "Distribution of Ores in Space and Time," which deals with the geographic distribution of the ores, the association of ore deposits with igneous rocks, metallogenetic epochs, and ore provinces. It is pointed out that there is direct conjunction of ores and plutonic intrusions; most of the ores are associated with granitic rocks but, as elsewhere, nickel, cobalt, and platinum ores are associated with basic and ultrabasic intrusions. Several instances of zonal arrangements of ores about intrusives are noted. An interesting table correlates metallogenesis with diastrophism and igneous intrusions in the various states and territories. The metallogenetic epochs recognized are: early Precambrian, late Middle Precambrian, Upper Cambrian, late Ordovician, late Silurian, late Middle Devonian, late Lower Carboniferous, late Permian, and Upper Cretaceous. In contrast with the Western Hemisphere, there is no Tertiary metallization.

Of the ores and minerals, coal leads in the value of production, followed by silver-lead ores, gold, iron ore, copper, and tin ore. Each ore and nonmetallic substance is considered state by state under subdivisions of primary and detrital deposits. Maps show the distribution of each mineral in each state, and many excellent diagrams present pertinent geological features. A bibliography, arranged by states, is given at the end of each chapter for the individual metals or minerals.

The method of treatment is somewhat cumbersome and repetitious, but one can learn about the occurrences of each metal or mineral in each of the states and territories of the Commonwealth. One is impressed by the great amount of detail that has been gathered about such a large number of occurrences of so many metals and minerals, and by the great labor that has gone into this painstaking compilation. It is a volume that will be continuously referred to by students of mineral deposits for a long time to come. The author, the editor, the contributors, and the Commonwealth of Australia are to be congratulated for such a worthy enterprise.

ALAN M. BATEMAN

Economic Mineral Deposits; by ALAN M. BATEMAN. Pp. xi, 916; 313 figs., numerous tables. New York and London, 1950 (John Wiley & Sons, Inc., and Chapman & Hall, Ltd., $7.50).—This book is an expanded and somewhat modified form of the first edition which was published in 1941 and contained 898 pages. It represents a commendable effort to keep abreast of the date of its preparation in the literature of the subject, as the index and text both demonstrate. The general organization remains the same as in the first edition. Tables have been revised (*e.g.* certain production and

reserve figures, and the excellent table of "geologic thermometers" on pp. 41-43) and certain illustrations improved.

In general, books on economic geology seek one of three purposes: the scientific, the practical, and a combination—and none of these terms is here invidiously applied. Each approach has much to be said for it and each is modified still further by the audience which the author has in mind. An audience of experienced geologists needs a handbook. A college or professional school student of mining or petroleum engineering, simultaneously taking courses that give him the elements of mining and extraction of minerals, needs chiefly a text outlining fundamentals of geology and applying them to his problems. In the case of seniors or early graduate students, presumably already well grounded in physical geology, petrology, and mineralogy, but not yet acquainted with the mineral industry as a whole, the text must frankly undertake to serve not so much as a specialized reference but rather as an exposition of the general subject of economic geology and to impart a background of the related fields in the mineral industries.

To the reviewer it is obvious that Professor Bateman, long experienced as a scientist, technologist, policy maker, and especially here as a teacher, has selected this third kind of audience—the student in the college or graduate school, rather than the experienced specialist or the young engineer. Against this purposive background it can be seen that the first edition of the book was excellently designed; the present revision serves this objective even better. It reviews such classic concepts as mineral deposit classification, oil field carbon ratios, coal alteration, metasomatism, and magmatic segregation (wisely included by the author under "Magmatic concentration") in a sufficiently basic and orthodox manner so that the beginner acquires the elements of a sound background. But it also deals in at least a summary fashion with the less well established, newer approaches to theory and practice, such as the origin of pegmatites, leached outcrops, stratigraphic control of mineralization, argillic alteration, and the leaching of the Lake Superior iron ores. In view of the audience anticipated, especially valuable departures from the classical texts of economic geology are the sections, appropriately short and generalized, on "Geophysical Prospecting" (pp. 376-397), "Extraction of Metals and Minerals" (pp. 398-415), and, for its broadly "cultural" value, the historical matter on the use of minerals and the development of the science (pp. 5-17). It is probable that the inclusion of such sections will be criticized by some who have not faced the problem of presenting economic geology in an introductory way, but too many young geologists go out into practice without any concept of the processes by which the very minerals they are seeking will be utilized and of the purposes they are to serve when recovered.

This requires some sacrifice of *depth* for the sake of attaining *breadth*, but the author's choice is well justified.

Sincerely written books, like sincere men, cannot be "all things to all people" and that fact, coupled with the author's own specialization in his life-work on ore deposits, explain some minor lacks. Reefs as oil field reservoirs are given the briefest mention. The Law of Hilt, though the best quantitative expression of metamorphism in medium-rank coals, is not referred to. But these, taken from the section on fuels, are selected criticisms rather than a random sampling: on the whole, it is surprising to find that almost every recently developed idea in the current of modern-day thought in economic geology is at least represented by a sentence or paragraph, and many receive a page or even a section. After all, this is no "Handbuch" of several volumes!

Three omissions of greater import, verging on short-comings in the eyes of the reviewer, may be recorded. First, for the general background essayed by the author, it would have been well to include at least some discussion of mineral laws and prevailing social concepts—for example, the contrast between the "claim" and the "concession" systems; the reviewer finds legal aspects mentioned only in connection with faulted veins (p. 348). Second, a brief description of geologic mine-mapping methods, with an illustration or two, would have been very desirable — somewhat analogous to the section concerning oil finding (pp. 672-678), though that, too, is necessarily very brief. Finally, more complete and extensive footnotes, however costly, would have lifted the text far above the introductory level; the summary references at the end of each chapter are too brief for the student who wishes to know more about Raibl in Yugoslavia, or El Oro in Mexico, the origin of pegmatites or the replacement of limestones. It is such footnotes that made Lindgren's "Mineral Deposits" and Emmons' "Geology of Petroleum" for years the standard reference works on ore deposits and petroleum. To add them to the volume here reviewed would probably expand it by 50 pages.

Withal there is a freshness and a skill in this impartial and unprejudiced survey of the field which is stimulating and beneficial in the highest sense. The volume will serve as an excellent beginning alike for the student who seeks primarily a general overview and for one who needs a basic approach from which to start specific work in ores or non-metals, coal or petroleum, international mineral economics or local property valuation. In brief, it is an excellent, up-to-date text and a useful reference. To say that it is an even better volume than the first edition is high praise indeed. The author and the publishers are to be heartily congratulated on an ambitious undertaking, well carried out.

CHARLES H. BEHRE, JR.

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CONTENTS

Radiocarbon Dating of Late-Pleistocene Events
Richard Foster Flint and Edward S. Deevey, Jr. 257

Comments on Radiocarbon Dating for Samples from the British Isles ..... *H. Godwin* 301

The Occurrence of Chrysoberyl at Greenfield, New York ..... *Robert A. Navias and John H. Ostrom* 303

Frost-Heaved Tussocks in Massachusetts
R. S. Sigafoos and D. M. Hopkins 312

A Bison from Eastern Washington
E. W. Tipper, Z. V. Jiuba, and R. L. Konizeski 318

REVIEWS

The Geology of the Commonwealth of Australia; by Sir T. W. Edgeworth David, edited by W. R. Browne...*John Rodgers and Alan M. Bateman* 326

Economic Mineral Deposits; by Alan M. Bateman...*Charles H. Behre, Jr.* 326

Publications Recently Received 326

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